Sandy Lake and Little Sandy Lake Monitoring (2010-2017)

Prepared by:
Darren J. Vogt
Environmental Director

Technical Report 18-05
January 2018

1854 Treaty Authority
4428 Haines Road
Duluth, MN 55811
218-722-8907
www.1854treatyauthority.org

Sandy Lake and Little Sandy Lake Monitoring (2010-2017)

Introduction

Under an agreement between the Bois Forte Band of Chippewa and the United States Steel Corporation-Minnesota Ore Operations, a monitoring program was completed in 2010-2014 at Sandy Lake and Little Sandy Lake. The United States Steel Corporation provided funding support for monitoring activities during these years. The 1854 Treaty Authority, in support of the Bois Forte Band and at their request, completed the monitoring work. Although the agreement was not extended into 2015-2017, the 1854 Treaty Authority continued the program.

Sandy Lake and Little Sandy Lake, also known locally as the Twin Lakes, historically have produced good stands of wild rice. Wild rice harvesters utilized the lakes when suitable crops were present. A lake survey in 1966 indicated moderately dense to dense stands covering both lakes. Rice production generally declined through the 1970s and 1980s, with little or no rice found in the lakes during a 1987 survey. Rice production has since remained poor. The lakes are located downstream of the tailings basin at the U.S. Steel Minntac iron ore operation. Construction of the tailings basin began in 1966. The resulting changes to water quantity and/or water quality in the system may have impacted wild rice in the Twin Lakes. Construction of a seepage collection system completed in late 2010 and other possible actions at the tailings basin may change the conditions in the Twin Lakes. With that in mind, monitoring activities were completed in 2010-2017 to document conditions in the lakes.

Monitoring activities completed in 2010-2017 have included:

- water depth recording
- inlet and outlet field surveys
- water sampling
- vegetation surveys
- aerial surveys

This report summarizes results from monitoring activities from all eight years. Previous reports contain similar information from monitoring activities completed in earlier years.

General Information

Sandy Lake (MN Department of Natural Resources # 69-0730) and Little Sandy Lake (MN Department of Natural Resources # 69-0729) are located north of Virginia, Minnesota in Township 59N, Range 18W, Sections 2, 3, 10, 11. Sandy Lake has a surface area of 121 acres, and Little Sandy Lake has a surface area of 89 acres. Please see Figures 1-3 for maps and an aerial photograph of the lakes.

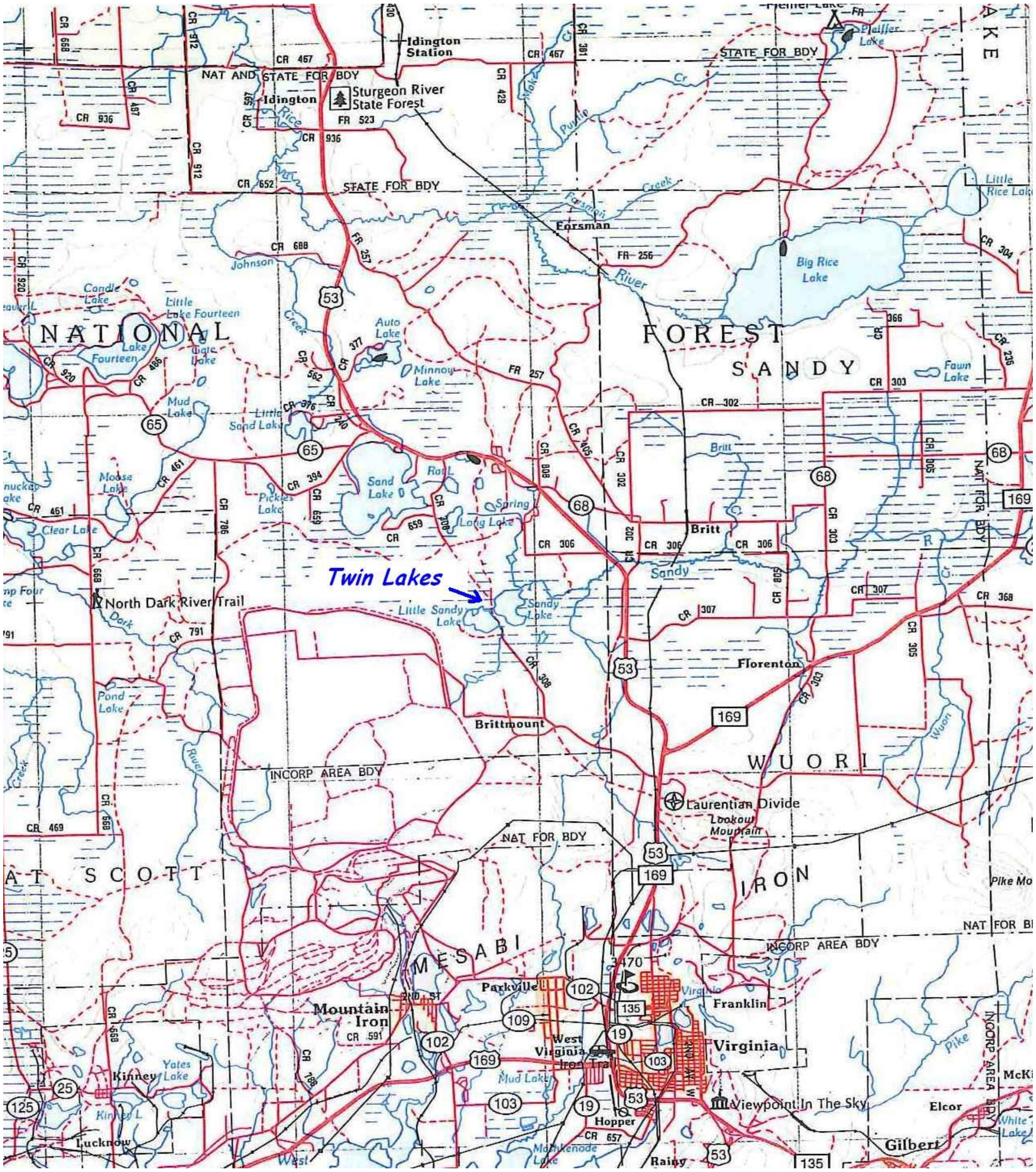

Figure 1: Sandy Lake and Little Sandy Lake (general vicinity and location)

Minnesota Atlas and Gazetteer, DeLorme, 1994

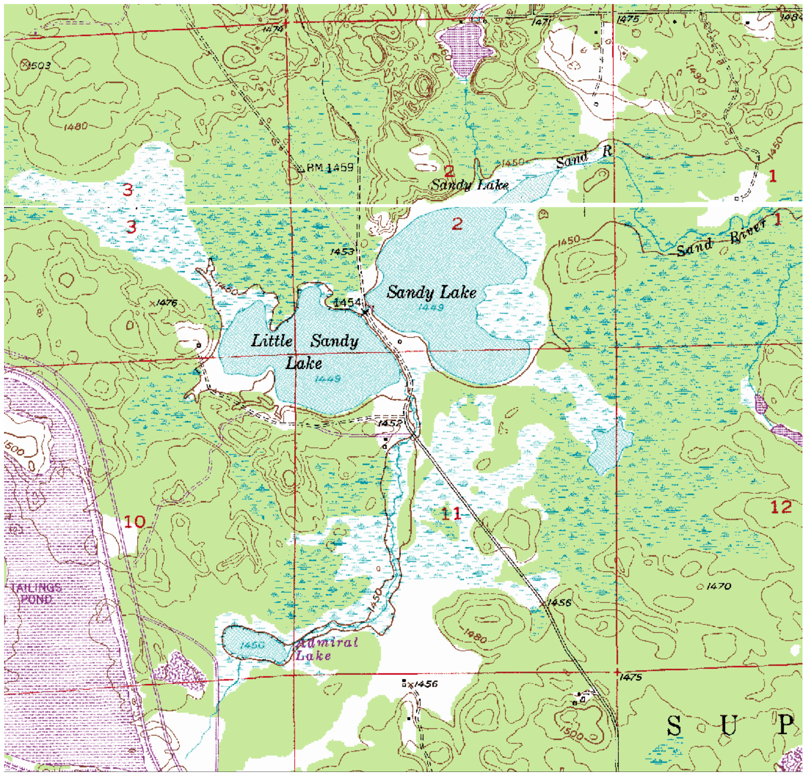

Figure 2: Sandy Lake and Little Sandy Lake (topographic map)
U.S. Geological Survey and Minnesota DNR

Figure 3: Sandy Lake and Little Sandy Lake (8/13/2015 imagery)

Most of the land around the lakes is in federal ownership and managed by the U.S. Forest Service, Superior National Forest. Some parcels of private ownership are located on the northeast shoreline of Sandy Lake and surrounding the outlet. Please see Figure 4.

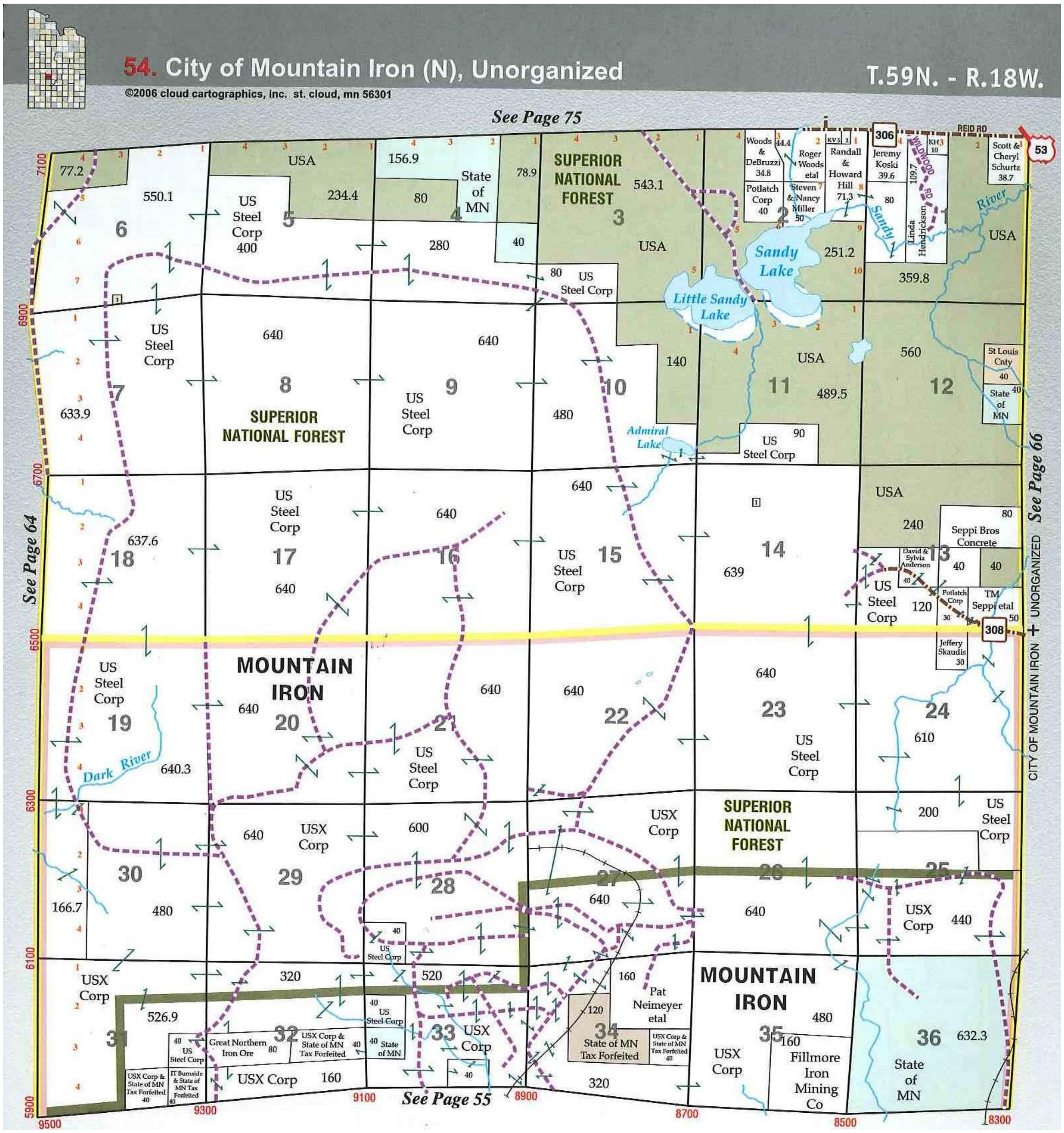

Figure 4: Sandy Lake and Little Sandy Lake (land ownership)
St. Louis County, MN, 2007 Land Atlas and Plat Book, Cloud Cartographics

Current access to the lakes is somewhat difficult. A narrow road extending from County Road 306 leads to the north side of the lakes, but crosses some private property. An informal truck trail provides a carry-down canoe access to the north shoreline of Sandy Lake. An alternative option is to utilize the existing road/trail to the bridge between the lakes. This trail was largely underwater in 2010-2017 and in many previous years, and access requires chest waders. Please see Appendix 1 for photographs of access points in 2017.

Sandy Lake and Little Sandy Lake (Twin Lakes) are located immediately downstream of the tailings basin for U.S. Steel's Minntac iron ore operation. Please see Figure 5.

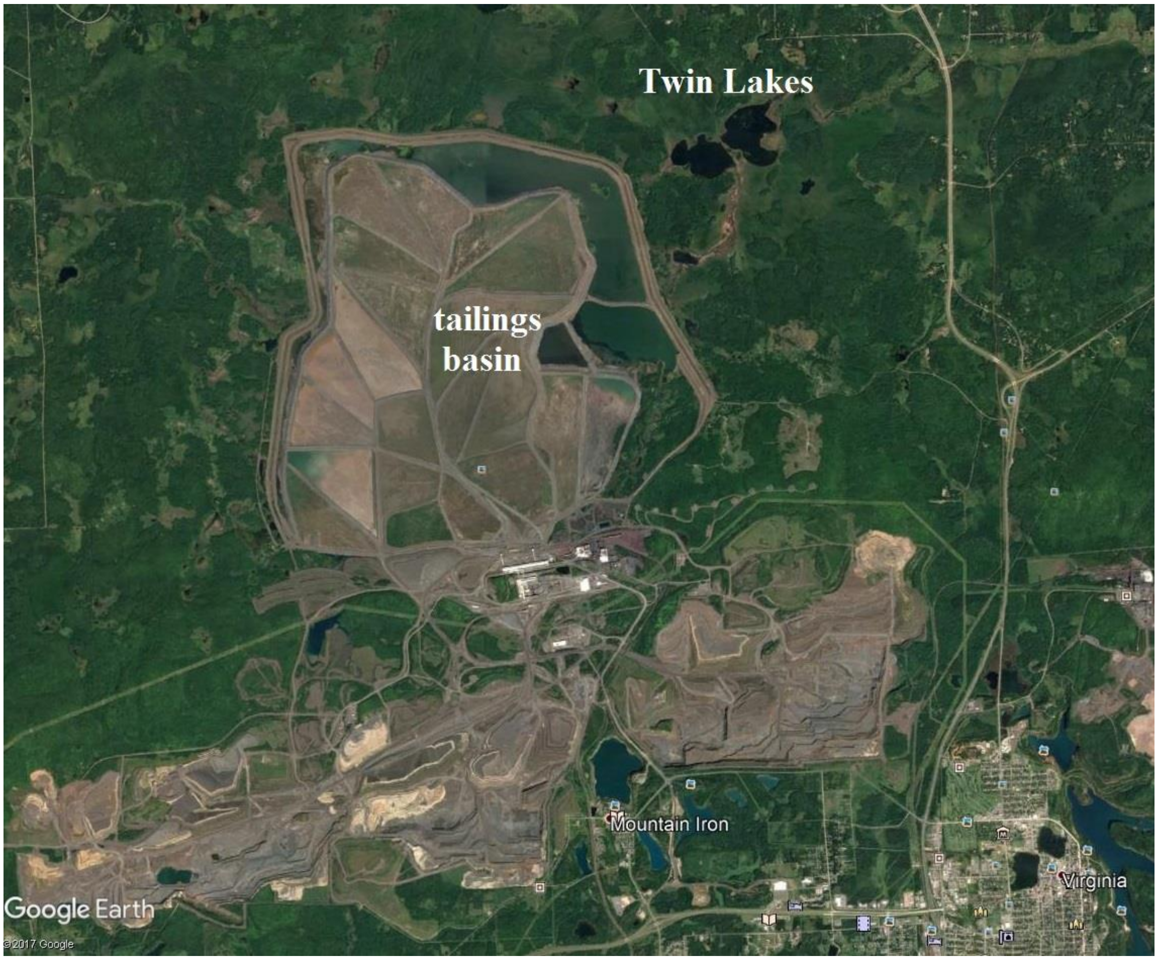

Figure 5: U.S. Steel Minntac and Twin Lakes (8/13/2015 imagery)

Water Depths

A trail and bridge bisect the connection between Sandy and Little Sandy lakes. A water depth gauge is attached to the northwest corner of the concrete bridge support. Data obtained from the Minnesota Department of Natural Resources indicates that the gauge was installed in 1991, with an elevation of 1447.1 feet above mean sea level (NGVD 29) at the zero reading on the gauge. A surveyed benchmark with an elevation of 1453.93 feet above mean sea level (NGVD 29), marked by a chiseled square in the concrete bridge support above the depth gauge, was established by the Minnesota Department of Transportation in 2008.

A local consulting firm (SEH) was retained under this monitoring project in 2010 to complete a survey to relate the depth gauge to elevation. Another benchmark was established in the same location on top of the concrete bridge support and marked by an "X" in the concrete. This benchmark has an elevation of 1454.86 feet above sea level (NAVD 88). The zero reading on the depth gauge is 1448.03 feet above mean sea level (NAVD 88). It should be noted that the two known surveyed benchmarks differ by 0.93 feet (1454.86 – 1453.93). This is due to use of the different vertical datum systems, National Geodetic Vertical Datum of 1929 (NGVD 29) versus North American Vertical Datum of 1988 (NAVD 88).

Utilizing the existing depth gauge (and identical replacement installed 11/29/2016 by the 1854 Treaty Authority) on the bridge support, water depth readings were recorded approximately every two weeks May through early November each year in 2010-2017. The graph in Figure 6 outlines water elevations at the Twin Lakes in 2010-2017. Some fluctuations may have been missed and not indicated on the graph with only periodic depth readings. The elevations reported are based on the benchmark established by SEH in 2010, since NAVD 88 is the current standard typically utilized. Across this time, the highest water reading was 1452.52 feet above mean sea level (5/15/2014), and the lowest was 1450.25 feet above mean sea level (8/1/2017), a difference of 2.27 feet.

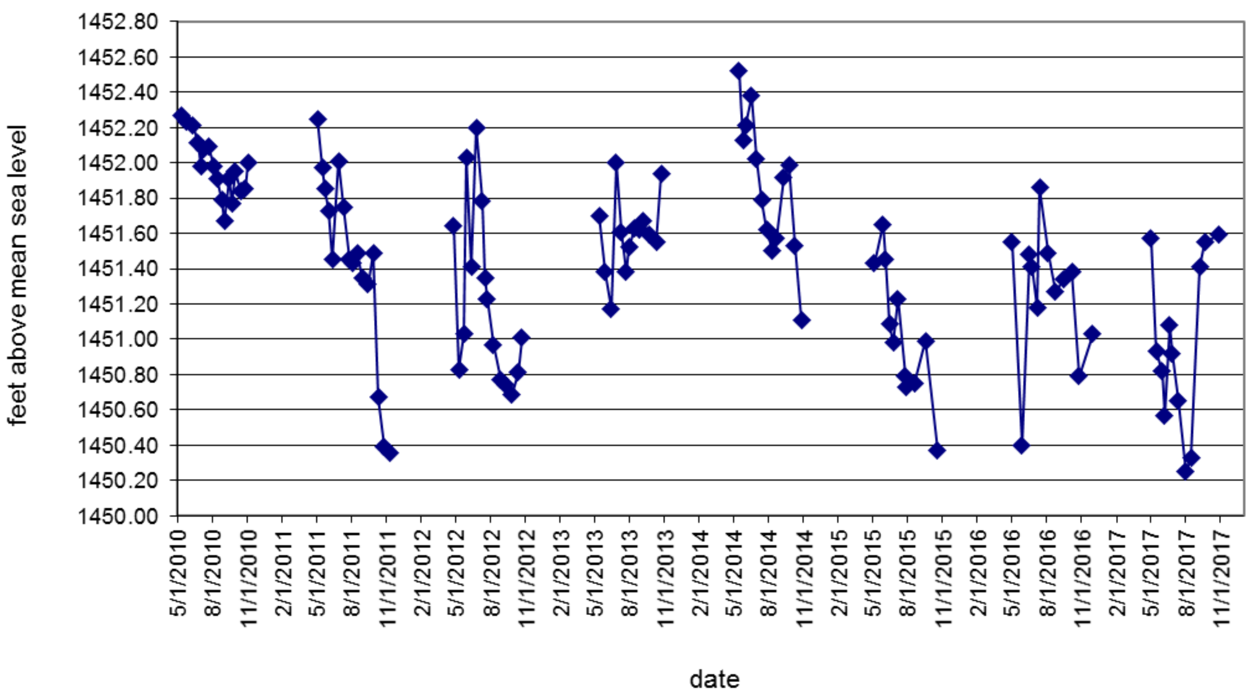

Figure 6: Water Elevation at the Twin Lakes in 2010-2017

A few readings are also available from visits completed in 2006-2008: 1451.71 (8/1/2006); 1451.48 (7/31/2007); 1451.83 (8/6/2008) feet above mean sea level based on the 2010 benchmark. Communication with the Minnesota Department of Natural Resources indicated that limited water level readings from the 1980s and 1990s may be on file at local offices. Under a separate initiative managed by U.S. Steel, an automatic data logger was installed adjacent to the bridge to track changes in water depth in 2013-2017. This data is not included in this report.

Water depth has a major influence on the success of wild rice. Wild rice grows in a variety of water depths, but 1-3 feet is typically considered prime conditions. During the vegetation surveys conducted on September 1, 2010 and June 25-26, 2013 water depths were recorded at every survey point. In the 2010 survey, mean water depths were 3.83 feet (range of 1.50-4.50 feet) in Sandy Lake and 4.23 feet (range of 2.25-5.00 feet) in Little Sandy Lake. In the 2013 survey, mean water depths were 4.07 feet (range of 1.50-5.00 feet) in Sandy Lake and 4.55 feet (range of 2.75-5.75 feet) in Little Sandy Lake.

In 2017, water levels were generally lower than previous years of this monitoring program through mid-August. Water levels declined from May until an increase in mid-June. Water levels then decreased into August, and included the lowest water level observed during this program on 8/1/2017. Water levels increased mid to late August and through October.

Besides upstream releases (surface and ground water) from the tailings basin and outlet conditions (such as presence of beaver dams), precipitation also impacts water levels in the Twin Lakes. Available data from the Minnesota State Climatology Office was utilized in Table 1 to summarize monthly precipitation near the Twin Lakes from May to October in 2010-2017. The precipitation data reported is based on the nearest available information reported for each month. Average monthly precipitation in inches reported for Virginia, MN is 2.73 in May, 4.64 in June, 3.87 in July, 3.74 in August, 3.44 in September, and 2.45 in October (www.weather.com). Utilizing this available information, total precipitation near the Twin Lakes was as follows:

- 23.94 inches (3.07 inches above average) from May to October 2010
- 13.73 inches (7.14 inches below average) from May to October 2011
- 23.38 inches (2.51 inches above average) from May to October 2012
- 18.38 inches (2.49 inches below average) from May to October 2013
- 21.94 inches (1.07 inches above average) from May to October 2014
- 22.10 inches (1.23 inches above average) from May to October 2015
- 25.70 inches (4.83 inches above average) from May to October 2016
- 26.90 inches (6.03 inches above average) from May to October 2017

Table 1: Monthly Precipitation near the Twin Lakes in May to October (2010-2017)

Month	Township, Range, Section	Distance from Twin Lakes	Precipitation (inches)
May 2010	59N 17W section 18	2 miles	2.51
June 2010	59N 17W section 18	2 miles	4.06
July 2010	59N 17W section 18	2 miles	6.69
August 2010	59N 17W section 18	2 miles	3.52
September 2010	58N 18W section 33	10 miles	4.91
October 2010	58N 18W section 33	10 miles	2.25
May 2011	59N 17W section 18	2 miles	2.80
June 2011	59N 17W section 18	2 miles	3.38
July 2011	60N 17W section 32	3 miles	1.28
August 2011	59N 17W section 18	2 miles	2.61
September 2011	59N 17W section 18	2 miles	2.04
October 2011	59N 17W section 18	2 miles	1.62
May 2012	59N 17W section 4	4 miles	7.10
June 2012	59N 17W section 18	2 miles	5.11
July 2012	60N 17W section 32	3 miles	6.67
August 2012	59N 17W section 4	4 miles	1.47
September 2012	59N 17W section 4	4 miles	1.05
October 2012	58N 18W section 33	10 miles	1.98
May 2013	59N 17W section 4	4 miles	2.44
June 2013	59N 17W section 4	4 miles	5.84
July 2013	59N 17W section 4	4 miles	3.51
August 2013	59N 17W section 4	4 miles	2.02
September 2013	59N 17W section 4	4 miles	1.44
October 2013	58N 18W section 33	10 miles	3.13
May 2014	59N 17W section 4	4 miles	4.03
June 2014	59N 17W section 4	4 miles	7.45
July 2014	59N 17W section 4	4 miles	4.35
August 2014	59N 17W section 4	4 miles	2.51
September 2014	58N 17W section 5	6 miles	1.91
October 2014	58N 18W section 33	10 miles	1.69
May 2015	59N 17W section 4	4 miles	4.89
June 2015	59N 17W section 4	4 miles	4.71
July 2015	59N 17W section 4	4 miles	2.10
August 2015	59N 17W section 4	4 miles	4.67
September 2015	59N 17W section 4	4 miles	3.24
October 2015	59N 17W section 4	4 miles	2.49
May 2016	59N 17W section 4	4 miles	1.66
June 2016	59N 17W section 4	4 miles	7.69
July 2016	59N 17W section 4	4 miles	4.28
August 2016	59N 17W section 4	4 miles	5.73
September 2016	59N 17W section 4	4 miles	4.89
October 2016	59N 17W section 4	4 miles	1.45
May 2017	59N 17W section 4	4 miles	2.86
June 2017	59N 17W section 4	4 miles	5.93
July 2017	58N 18W section 33	10 miles	1.06
August 2017	58N 18W section 33	10 miles	8.44
September 2017	58N 18W section 33	10 miles	6.11
October 2017	58N 18W section 33	10 miles	2.50

Minnesota State Climatology Office, Minnesota Climatology Working Group

Inlet and Outlet Field Surveys

Beaver activity can alter water levels and flow in a system, and potentially negatively impact wild rice. To document beaver activity and other general features, field surveys were completed on the inlet and outlet (Sand River) of the Twin Lakes in 2010, and only on the outlet in 2011-2017. The Minntac tailings basin is the headwaters of the Twin Lakes, with a creek entering the southeast corner of Little Sandy Lake and presumably other surface and ground water also entering the system. The Sand River leaves the northeast corner of Sandy Lake. A field survey was conducted on June 27, 2017 down the outlet of the Twin Lakes to the U.S. Highway 53 crossing. Beaver activity was the focus of the survey. Only inactive dams and lodges were present in this portion of the outlet, except for one beaver dam observed with some fresh activity but open in the middle allowing for water flow. All other dams had been cleared and opened. One site with an inactive beaver dam has grown cattails across the river, restricting flow to small openings. Other underwater berms remained, but none were holding or controlling water levels at the time of the survey.

In addition to water entering the system from the tailings basin, the beaver activity on the outlet may also be a factor in higher water levels in the Twin Lakes. It is likely that the water levels in 2010-2017 and in recent history are contributing to the negative impacts on wild rice. Besides addressing releases from the tailings basin, beaver management (trapping, dam removal) down the outlet should be a consideration to reduce water levels in the Twin Lakes. U.S. Steel contracted with trappers from the U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) to complete beaver and dam removal beginning in spring 2015. In 2015, approximately 60 beavers were removed along with numerous dams done by hand or with explosives. Beaver activity in 2016 was minimal during checks by the APHIS crew. In 2017, crews removed a few beavers and did additional cleaning at three pinch points in the outlet. U.S. Steel plans to continue contracting for similar efforts in 2018 (*U.S. Steel Minntac Twin Lakes Wild Rice Restoration Opportunities Plan 2017 Annual Report, Northeast Technical Services Inc., December 29, 2017*). Ongoing beaver management and dam removal may be needed to maintain a clear outlet.

Water Sampling and Analysis

Four water sampling locations were established in 2010. Figure 7 shows the locations of the sampling points. The locations were set in a downstream gradient and identified as:

- Twin 1 - inlet at Little Sandy Lake
- Twin 2 - middle of Little Sandy Lake
- Twin 3 - middle of Sandy Lake
- Twin 4 - outlet at Sandy Lake

Water samples were collected monthly from May through October in 2010-2014, and bi-monthly (June, August, October) in 2015-2017. Analyses were completed by Pace Analytical (formerly Era Laboratories, Inc.) in Duluth, MN. Results from 2017 are included in Table 2, and annual results of the analyses from all years (2010-2017) are included in Appendix 2.

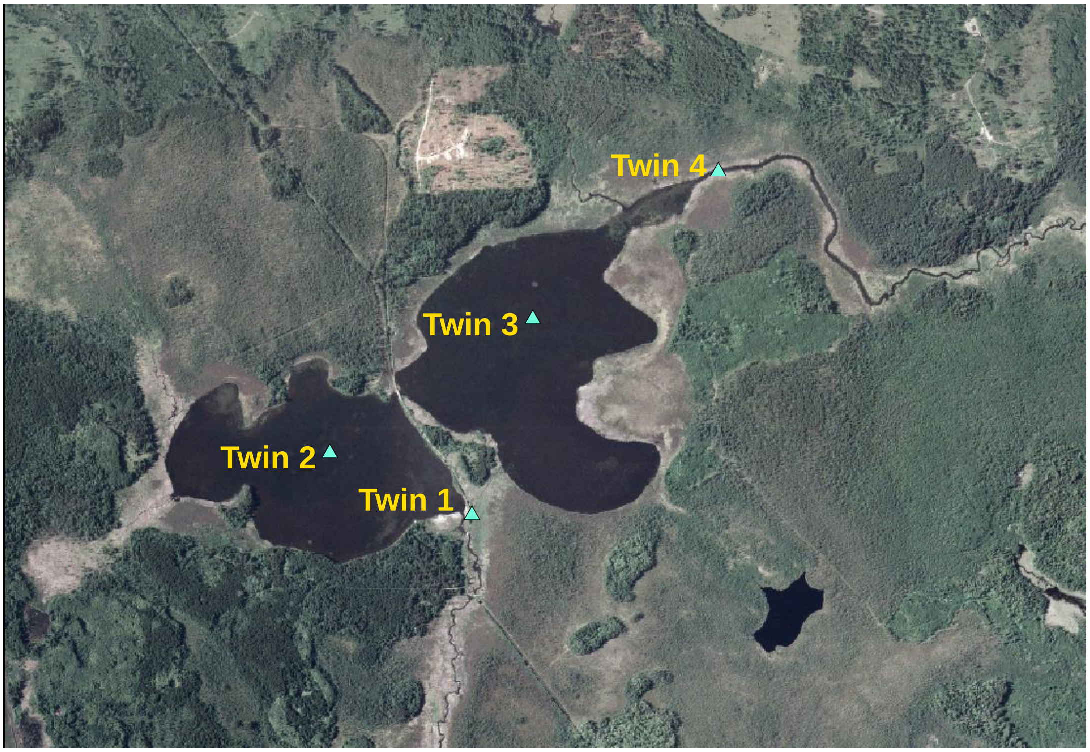

Figure 7: Water Sampling Points for the Twin Lakes

Table 2: Water Sample Analysis in the Twin Lakes (2017)

Twin 1	6/27/2017	8/15/2017	10/26/2017	units
alkalinity (as CaCO3)	137	283	180	mg/L
chloride	36.9	93.8	50.6	mg/L
color	150	70.0	200	Pt-Co
nitrogen, ammonia	0.14	0.12	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.82	ND	0.68	mg/L
nitrogen, total kjeldahl	0.81	ND	0.68	mg/L
pH - lab	7.1	8.1	7.4	SU
phosphorus, total	0.025	0.011	0.025	mg/L
solids, suspended volatile	1.6	2.4	1.0	mg/L
solids, total dissolved	536	1230	724	mg/L
solids, total suspended	1.6	4.6	1.0	mg/L
specific conductance	823	1740	998	umhos/cm
sulfate	251	589	297	mg/L
turbidity	2.3	1.7	3.8	NTU

Twin 2	6/27/2017	8/15/2017	10/26/2017	units
alkalinity (as CaCO3)	141	206	165	mg/L
chloride	23.5	37.7	30.9	mg/L
color	150	100	150	Pt-Co
nitrogen, ammonia	0.11	ND	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.71	0.85	0.70	mg/L
nitrogen, total kjeldahl	0.71	0.85	0.70	mg/L
pH - lab	7.1	8.8	8.2	SU
phosphorus, total	0.014	0.012	0.011	mg/L
solids, suspended volatile	1.2	ND	1.0	mg/L
solids, total dissolved	436	602	538	mg/L
solids, total suspended	1.4	ND	ND	mg/L
specific conductance	647	978	745	umhos/cm
sulfate	170	242	189	mg/L
turbidity	1.3	1.1	1.2	NTU

Twin 3	6/27/2017	8/15/2017	10/26/2017	units
alkalinity (as CaCO3)	104	146	129	mg/L
chloride	21.6	24.6	27.8	mg/L
color	175	125	200	Pt-Co
nitrogen, ammonia	0.14	ND	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.84	0.89	0.77	mg/L
nitrogen, total kjeldahl	0.84	0.89	0.77	mg/L
pH - lab	7.0	8.6	8.1	SU
phosphorus, total	0.016	0.016	0.015	mg/L
solids, suspended volatile	1.0	ND	ND	mg/L
solids, total dissolved	348	422	432	mg/L
solids, total suspended	ND	ND	1.2	mg/L
specific conductance	521	648	610	umhos/cm
sulfate	131	132	145	mg/L
turbidity	1.3	1.2	2.3	NTU

Twin 4	6/27/2017	8/15/2017	10/26/2017	units
alkalinity (as CaCO3)	92.9	105	120	mg/L
chloride	19.6	19.7	26.2	mg/L
color	250	100	200	Pt-Co
nitrogen, ammonia	ND	ND	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.75	0.73	0.70	mg/L
nitrogen, total kjeldahl	0.74	0.72	0.69	mg/L
pH - lab	6.8	8.1	7.9	SU
phosphorus, total	0.018	0.025	0.015	mg/L
solids, suspended volatile	ND	ND	ND	mg/L
solids, total dissolved	320	248	384	mg/L
solids, total suspended	1.2	1.2	1.4	mg/L
specific conductance	467	419	564	umhos/cm
sulfate	115	66.4	130	mg/L
turbidity	3.0	2.0	2.6	NTU

In comparison with other lakes containing wild rice in the region, some parameters are of note in the Twin Lakes. Most notable are elevated levels of alkalinity, chloride, total dissolved solids, specific conductance, and sulfate. Sulfate levels ranged from 210 mg/L to 661 mg/L across all samples in 2010, before the installation of the seep collection system at the U.S. Steel Minntac tailings basin. After the system was in operation, sulfate ranged from 61.4 to 561 mg/L in 2011, from 38 to 275 mg/L in 2012, from 36 to 650 mg/L in 2013, from 44 to 419 mg/L in 2014, from 45.6 to 590 mg/L in 2015, from 70.9 to 347 mg/L in 2016, and from 66.4 to 589 mg/L in 2017. Table 3 displays average sulfate concentrations at each sampling point in 2010-2017. A Minnesota water quality standard exists for sulfate of *"10 mg/L, applicable to water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels"* (Minnesota Rules, part 7050.0224, subp. 2).

Table 3: Average Sulfate Concentrations at Twin Lakes Sampling Points (ranges in parentheses)

	2010 average sulfate (mg/L)	2011 average sulfate (mg/L)	2012 average sulfate (mg/L)	2013 average sulfate (mg/L)	2014 average sulfate (mg/L)
Twin 1	483 (360-661)	357 (208-561)	207 (137-275)	355 (215-650)	301 (180-419)
Twin 2	353 (280-475)	164 (130-247)	144 (87-210)	195 (149-261)	172 (128-274)
Twin 3	280 (250-310)	118 (103-166)	97 (72.6-160)	129 (118-140)	114 (96-172)
Twin 4	234 (210-252)	84 (61.4-127)	66 (38-101)	89 (36-120)	70 (44-100)

	2015 average sulfate (mg/L)	2016 average sulfate (mg/L)	2017 average sulfate (mg/L)
Twin 1	460 (386-590)	289 (217-347)	379 (251-589)
Twin 2	295 (253-360)	177 (126-211)	200 (170-242)
Twin 3	217 (171-270)	130 (82.7-158)	136 (131-145)
Twin 4	145 (45.6-220)	114 (70.9-138)	104 (66.4-130)

To help determine if the seep collection system was a factor in reducing sulfate levels in the Twin Lakes at the start of operation in late 2010, paired two-sample, one-tailed t-tests were performed (alpha = 0.05) comparing data from 2010 to 2011. Analyses were based on water quality results from six samples taken at each location (Twin 1, Twin 2, Twin 3, Twin 4) per year.

On average, sulfate levels measured in 2011 were significantly less than sulfate levels measured in 2010 at sample locations Twin 2 (164.3 mg/L < 352.5 mg/L, $p = 0.0011$, $t = 5.72$), Twin 3 (117.5 mg/L < 279.5 mg/L, $p = 0.0001$, $t = 10.09$) and Twin 4 (83.9 mg/L < 234.2mg/L, $p = 0.0001$, $t = 11.07$). The average sulfate level measured at Twin 1 in 2011 was lower than the level measured in 2010 (356.7 mg/L < 482.3 mg/L), but the difference was not significant ($p = 0.0780$, $t = 1.67$). These analyses suggest a decrease in sulfate concentration at each sample location after the first year of seep collection operation.

From 2010-2017 (which includes the 2010 season before seep collection), sulfate levels have trended down slightly in the Twin Lakes (Figure 8), indicating some benefit from seep collection efforts. After the seep collection system began operation, sulfate levels in 2011-2017 have varied and showed a trend upward (Figure 9).

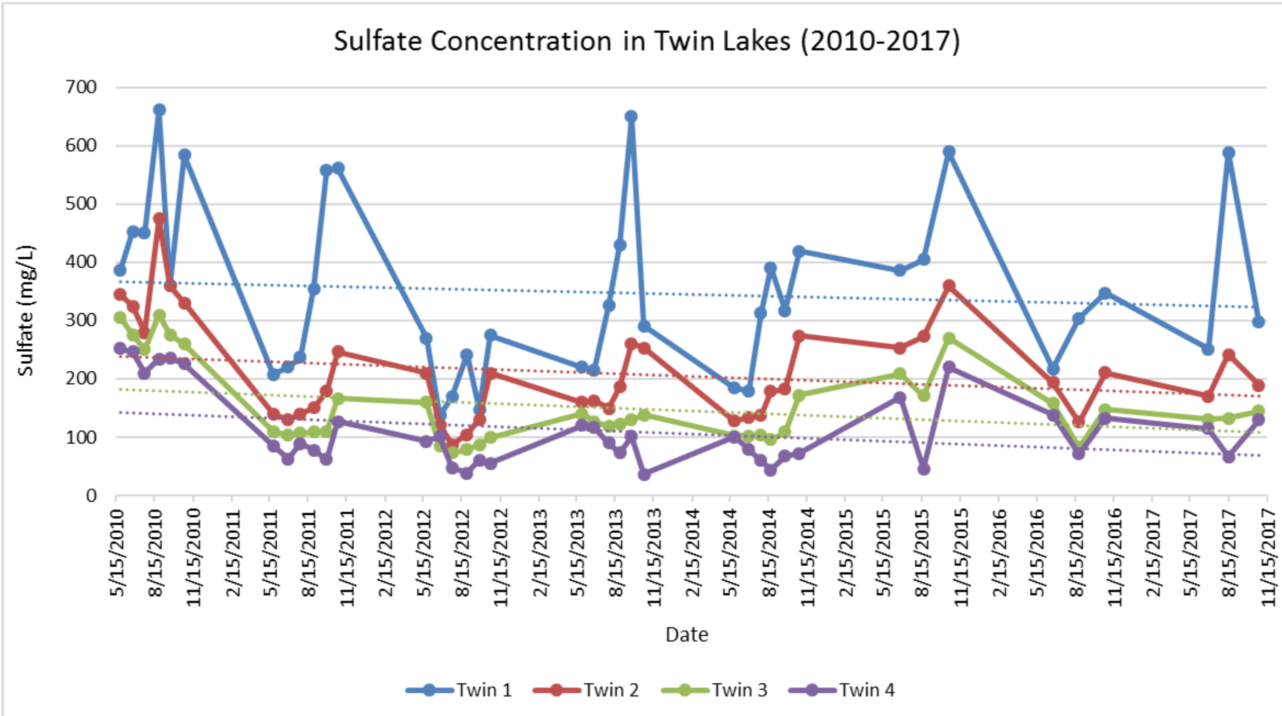

Figure 8: Sulfate Concentration in Twin Lakes (2010-2017)

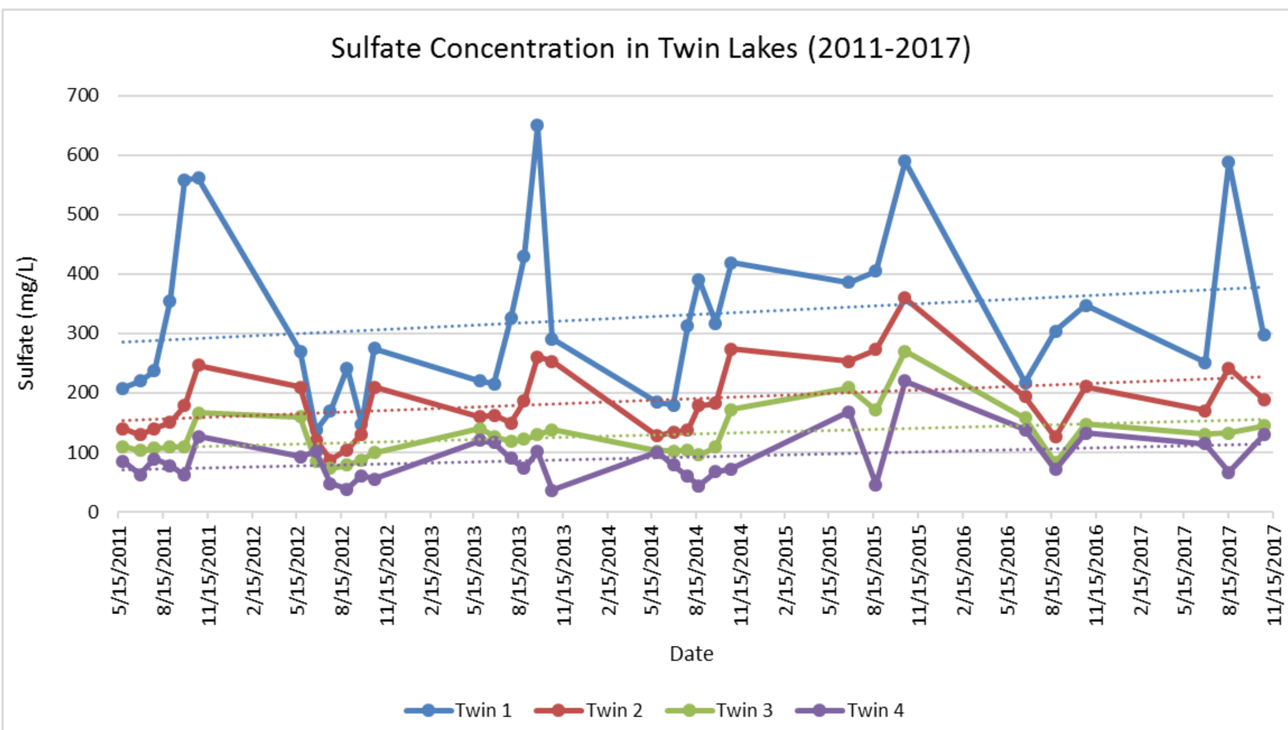

Figure 9: Sulfate Concentration in Twin Lakes (2011-2017)

In addition to monthly water sampling in the Twin Lakes, one sampling event occurred at three locations each October in 2010-2017 in the system downstream to Lake Vermilion. Sampling was completed in the Sand River (State Highway 169 crossing), Pike River (County Road 367), and the Pike River Flowage (State Highway 1 public access). Sampling locations are shown in Figure 10.

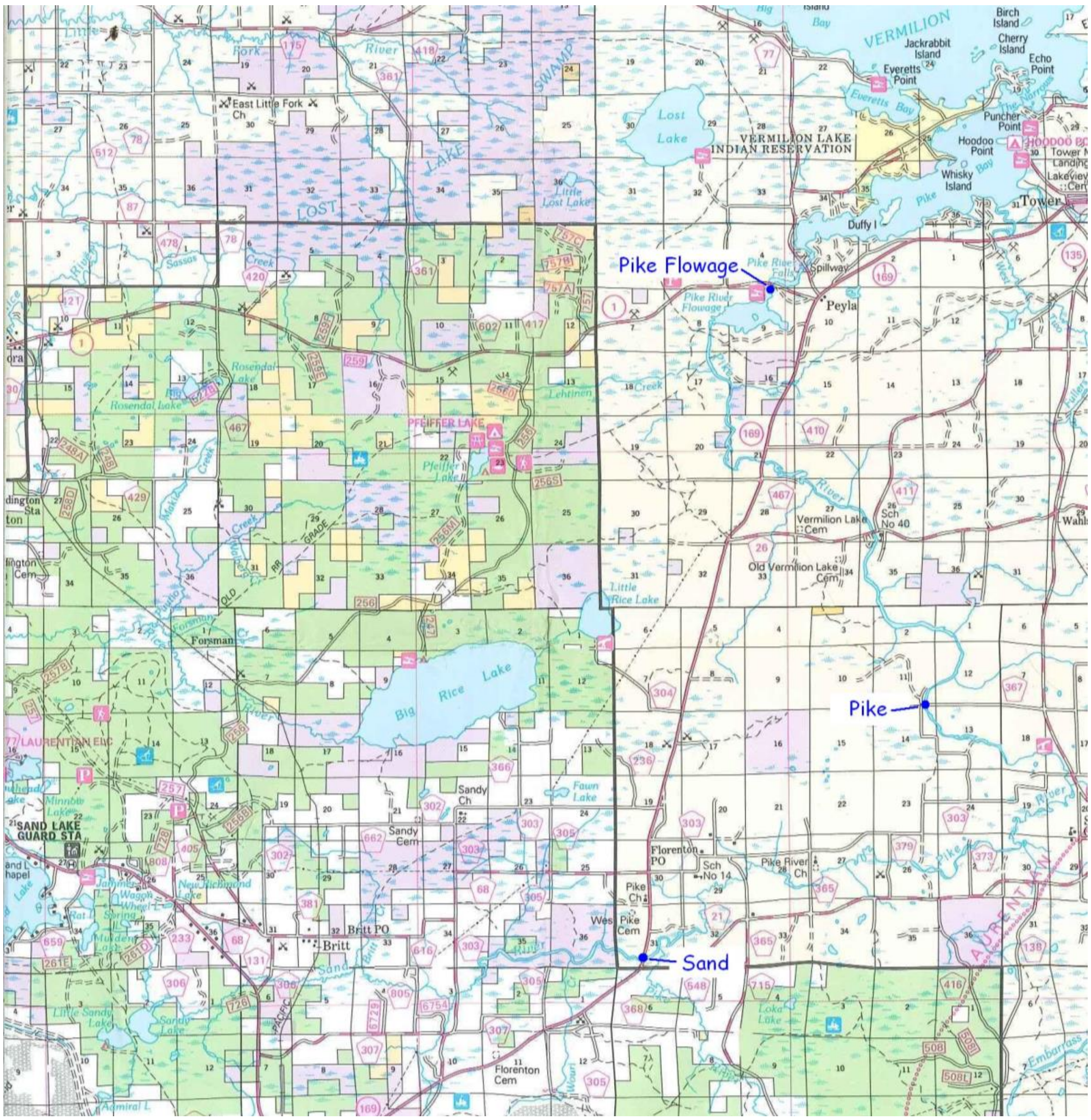

Figure 10: Water Sampling Points in the Sand River, Pike River, and Pike River Flowage
United States Department of Agriculture, U.S. Forest Service, Superior National Forest map, 2003

Table 4 displays analysis results in 2017, and Appendix 2 includes annual results of the analyses from all years (2010-2017) for the downstream sampling locations. Sample analysis indicated generally declining levels of several parameters including alkalinity, chloride, total dissolved solids, specific conductance, and sulfates moving downstream through the system. When sampling was conducted at all points on the same date, sulfate concentrations from the inlet at Little Sandy Lake to the Pike River Flowage ranged from 584-27 mg/L on 10/25/2010, from 561-19 mg/L on 10/26/2011, from 275-15 mg/L on 10/22/2012, from 291-7.1 mg/L on 10/23/13, from 419-11 mg/L on 10/27/14, from 590-31.9 mg/L on 10/19/2015, from 347-17.9 mg/L on 10/25/2016, and from 297 to 15.1 mg/L on 10/26/2017.

Table 4: Water Sample Analysis in the Sand River, Pike River, and Pike River Flowage (2017)

10/26/2017	Sand	Pike	Pike Flowage	units
alkalinity (as CaCO3)	85.8	63.6	49.5	mg/L
chloride	26.1	16.4	13.5	mg/L
color	250	250	250	Pt-Co
nitrogen, ammonia	0.10	ND	ND	mg/L
nitrogen, nitrate + nitrite	ND	0.033	0.031	mg/L
nitrogen, total	0.98	0.96	0.88	mg/L
nitrogen, total kjeldahl	0.97	0.93	0.85	mg/L
pH - lab	7.4	7.5	7.5	SU
phosphorus, total	0.035	0.027	0.026	mg/L
solids, suspended volatile	5.2	10.6	1.4	mg/L
solids, total dissolved	224	140	172	mg/L
solids, total suspended	8.0	45.2	8.4	mg/L
specific conductance	335	231	188	umhos/cm
sulfate	36.9	19.2	15.1	mg/L
turbidity	7.8	17.5	6.2	NTU

Vegetation Surveys

Known aquatic vegetation surveys were completed in 1966 and 1987 at the Twin Lakes by the Minnesota Division of Game and Fish, and Minnesota Department of Natural Resources respectively. The 1966 survey described Sandy Lake with dense wild rice over the entire lake, and Little Sandy Lake with moderately dense rice over the entire lake. The report also mentions that the wild rice is harvested at the lakes when the crop is adequate. Results from the 1987 survey indicated that the aquatic vegetation changed little since the 1966 survey, with one noticeable exception. Wild rice for all practical purposes was absent from both lakes. Two other changes occurred: the water levels were considerably higher in 1987 than in 1966 (approximately 2 feet), and the water clarity improved dramatically (from 1.3 feet to approximately 6 feet). The report also describes the rice crop at Twin Lakes in some years from 1966 to 1987: 1966-fair, 1968-fair, 1970-good, 1972-good, 1973-fair, 1977-poor, 1978-poor, 1980-fair, 1981-fair, 1982-poor, 1984-poor, 1985-poor, 1986-poor, 1987-poor.

With the decline in wild rice abundance, some management activities were undertaken to improve production at the Twin Lakes. Beaver management (trapping, dam blasting) was conducted on the system periodically in the 1980s through the mid-1990s by the Minnesota Department of Natural Resources. In addition, information indicates that some wild rice seeding was conducted in 1991 and 1992. However, limited success in restoring wild rice was noted. Staff from the Minnesota Department of Natural

Resources report an area of sparse wild rice was found near the outlet in 1993, and believe that was the last time anything that could be referred to as a "bed of wild rice" was on the lakes. Wild rice was found only in trace quantities within the lakes in 2000 and 2001 by the Bois Forte Department of Natural Resources (reported in Minntac Water Inventory Reduction EIS, September 2004). The 1854 Treaty Authority conducted a survey to document wild rice presence on the Twin Lakes on August 1, 2006. Some individual wild rice plants were found along portions of the shoreline of Sandy Lake, and along portions of the north shore of Little Sandy Lake. Please see Figure 11.

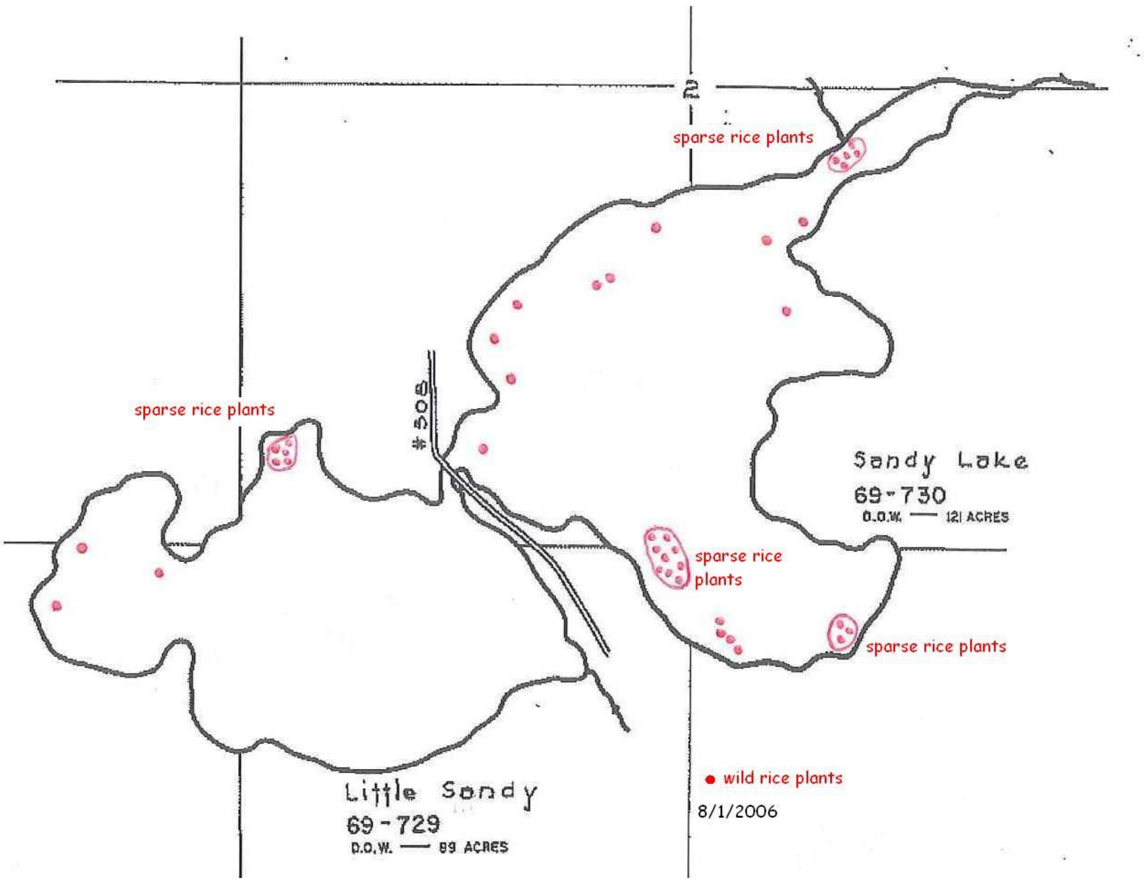

Figure 11: Wild Rice Locations in the Twin Lakes in 2006

Another field visit, but not a complete survey of both lakes, on July 31, 2007 found a few scattered wild rice plants along the west shoreline of Sandy Lake near the bridge. Please see Figure 12. No wild rice was evident viewing from the bridge on August 6, 2008.

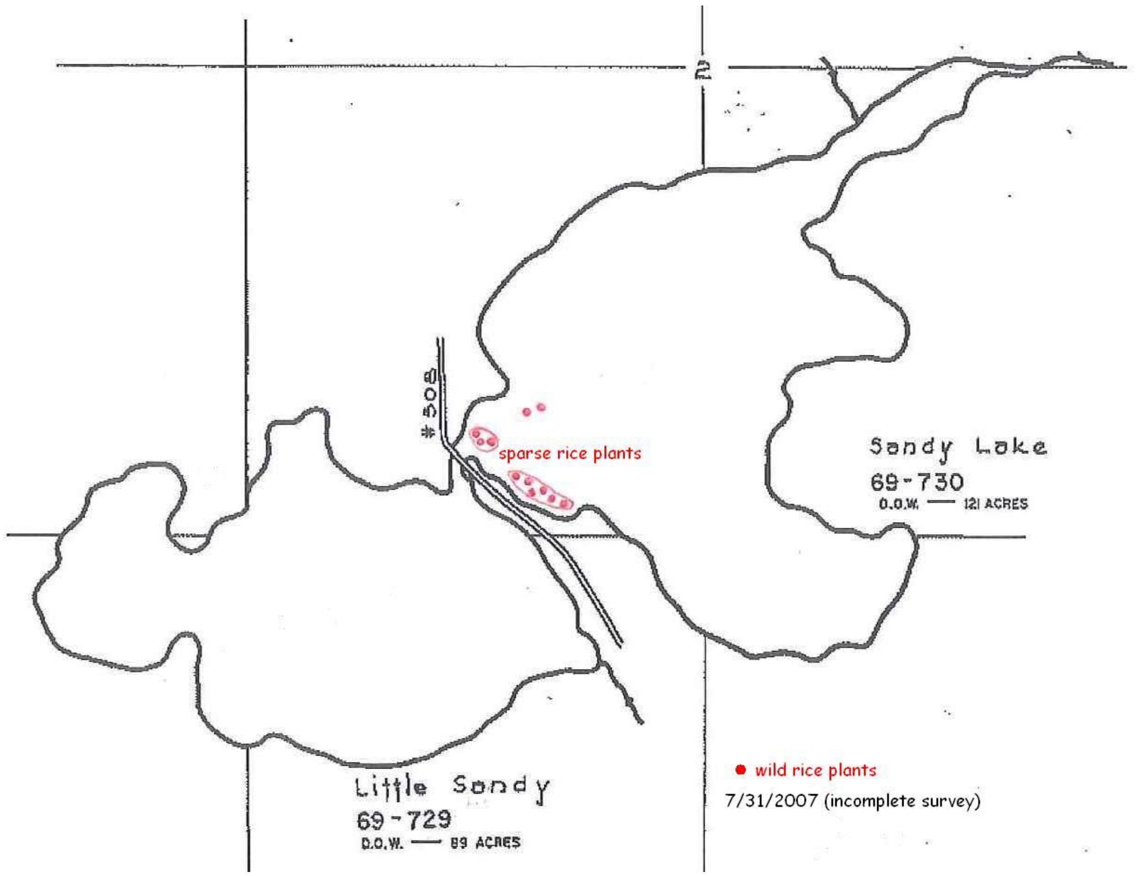

Figure 12: Wild Rice Locations in the Twin Lakes in 2007 (not complete survey of lakes)

To document conditions at the Twin Lakes, an aquatic vegetation survey was completed on both lakes on September 1, 2010. The survey was conducted by the Minnesota Department of Natural Resources Shallow Lakes Program, following their standard protocol for lake surveys. In general, the survey consisted of identifying aquatic vegetation (and recording other characteristics such as water depth, water clarity, and bottom type) at a grid of survey points across the lakes. Emergent and floating-leaf vegetation was identified by sight, and a sampling hook was used to gather submerged vegetation for identification. On the Twin Lakes, 49 survey points were established on Sandy Lake, and 44 points on Little Sandy Lake. The Minnesota Department of Natural Resources repeated the aquatic vegetation survey on June 25-26, 2013. Vegetation found and frequency observed at sampling points in the lakes during the 2010 and 2013 surveys are listed in Table 5. The Minnesota Department of Natural Resources has completed final reports for both vegetation surveys.

Table 5: Vegetation in the Twin Lakes in 2010 and 2013

Sandy Lake (9/1/2010)		Sandy Lake (6/26/2013)	
vegetation species	**frequency**	**vegetation species**	**frequency**
Muskgrass *(Chara spp.)*	75.5%	**Northern Water Milfoil** *(Myriophyllum sibiricum)*	52.1%
Northern Water Milfoil *(Myriophyllum sibiricum)*	36.7%	**Sago Pondweed** *(Stuckenia pectinata)*	39.6%
Sago Pondweed *(Stuckenia pectinata)*	34.7%	**Muskgrass** *(Chara spp.)*	37.5%
Coontail *(Ceratophyllum demersum)*	10.2%	**Greater Bladderwort** *(Utricularia vulgaris)*	25.0%
no vegetation found	10.2%	**Common Yellow Waterlily** *(Nuphar variegata)*	18.8%
Emergent Burreed Group *(Sparganium EM spp.)*	6.1%	**White-stem Pondweed** *(Potamogeton praelongus)*	8.3%
White Waterlily *(Nymphaea odorata)*	6.1%	**Flat-stem Pondweed** *(Potamogeton zosteriformis)*	6.3%
Greater Bladderwort *(Utricularia vulgaris)*	4.1%	**White Waterlily** *(Nymphaea odorata)*	6.3%
Fries Pondweed *(Potamogeton friesii)*	4.1%	**Narrowleaf Cattail Group** *(Typha angustifolia or glauca)*	4.2%
Bushy Pondweed *(Najas flexilis)*	4.1%	**no vegetation found**	4.2%
Narrowleaf Cattail Group *(Typha angustifolia or glauca)*	2.0%	**Coontail** *(Ceratophyllum demersum)*	4.2%
Clasping-leaf Pondweed *(Potamogeton richardsonii)*	2.0%	**Robbins Pondweed** *(Potamogeton robbinsii)*	2.1%
White-stem Pondweed *(Potamogeton praelongus)*	2.0%	**Curly-leaf Pondweed** *(Potamogeton crispus)*	2.1%
Watermoss Group *(Drepanocladus or Fontinalis spp.)*	2.0%	**Water Shield** *(Brasenia schreberi)*	2.1%

Little Sandy Lake (9/1/2010)		Little Sandy Lake (6/25/2013)	
vegetation species	**frequency**	**vegetation species**	**frequency**
Northern Water Milfoil *(Myriophyllum sibiricum)*	84.1%	**Northern Water Milfoil** *(Myriophyllum sibiricum)*	79.5%
Muskgrass *(Chara spp.)*	81.8%	**Sago Pondweed** *(Stuckenia pectinata)*	56.8%
Sago Pondweed *(Stuckenia pectinata)*	27.3%	**Greater Bladderwort** *(Utricularia vulgaris)*	31.8%
Fries Pondweed *(Potamogeton friesii)*	13.6%	**Coontail** *(Ceratophyllum demersum)*	20.5%
Coontail *(Ceratophyllum demersum)*	9.1%	**Common Yellow Waterlily** *(Nuphar variegata)*	15.9%
Greater Bladderwort *(Utricularia vulgaris)*	6.8%	**Muskgrass** *(Chara spp.)*	15.9%
Emergent Burreed Group *(Sparganium EM spp.)*	6.8%	**Narrowleaf Cattail Group** *(Typha angustifolia or glauca)*	4.5%
Narrowleaf Cattail Group *(Typha angustifolia or glauca)*	4.5%	**Floatingleaf Burreed Group** *(Sparganium FL spp.)*	4.5%
Common Yellow Waterlily *(Nuphar variegata)*	2.3%	**Spikerush Group *(Eleocharis spp.)*** *(Eleocharis spp.)*	4.5%
		no vegetation found	2.3%

Present but not observed at any sample points: Wild Rice *(Zizania palustris)*, Pickerelweed *(Pontederia cordata)*, Arrowhead Group *(Sagittaria spp.)*, Bulrush Group *(Scirpus spp.)*

During the vegetation survey on September 1, 2010, specific locations containing wild rice were recorded. Two areas on Sandy Lake contained wild rice plants. Wild rice plants (<25) were located on the northeast arm toward the outlet. Additional wild rice plants (<50) were located on the southwest end of the lake. No wild rice was found in Little Sandy Lake in 2010. Please see Figure 13 for wild rice locations in 2010.

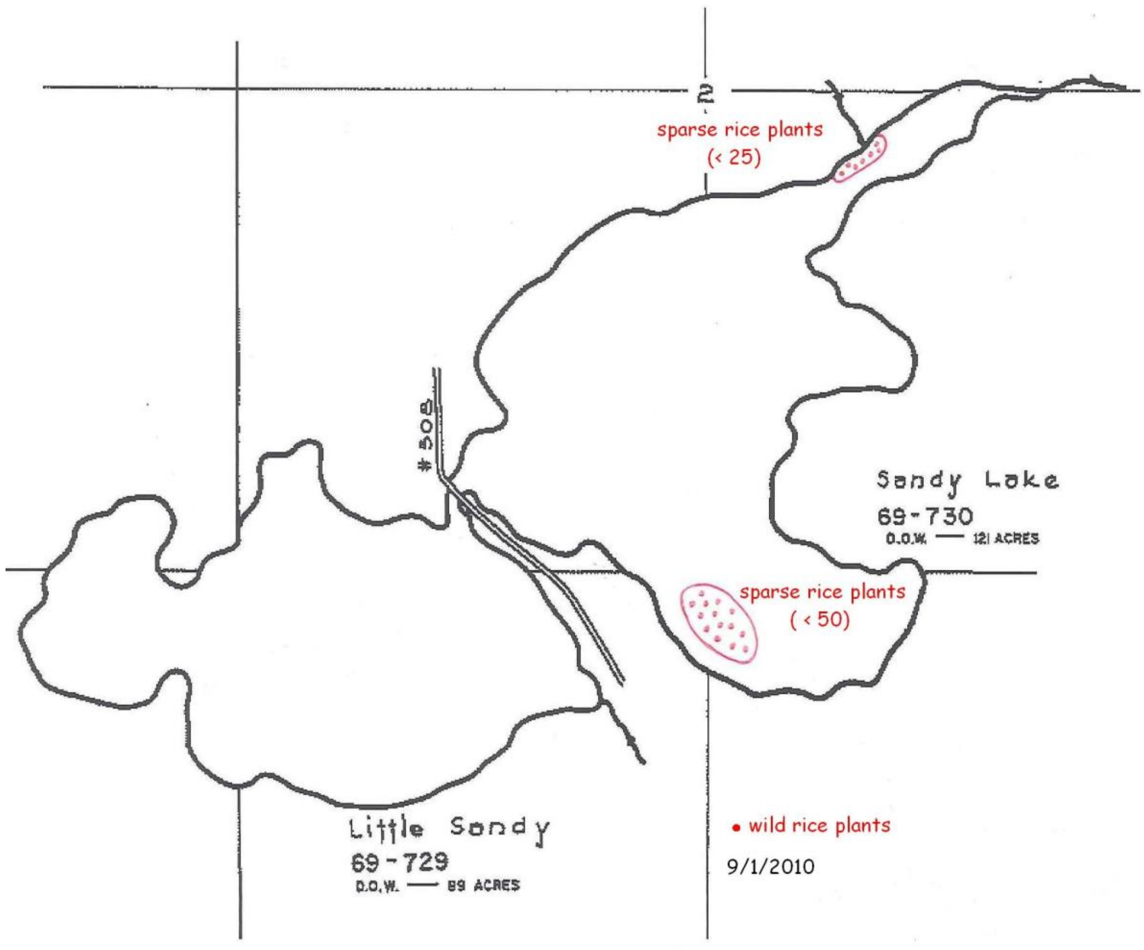

Figure 13: Wild Rice Locations in the Twin Lakes in 2010

A survey was conducted on August 29, 2011 to document wild rice presence on the lakes. Wild rice plants (<50) were located on the northeast arm of Sandy Lake toward the outlet. Additional wild rice plants (<40) were located on the southwest end of the lake. No wild rice was found in Little Sandy Lake in 2011. Please see Figure 14 for wild rice locations in 2011.

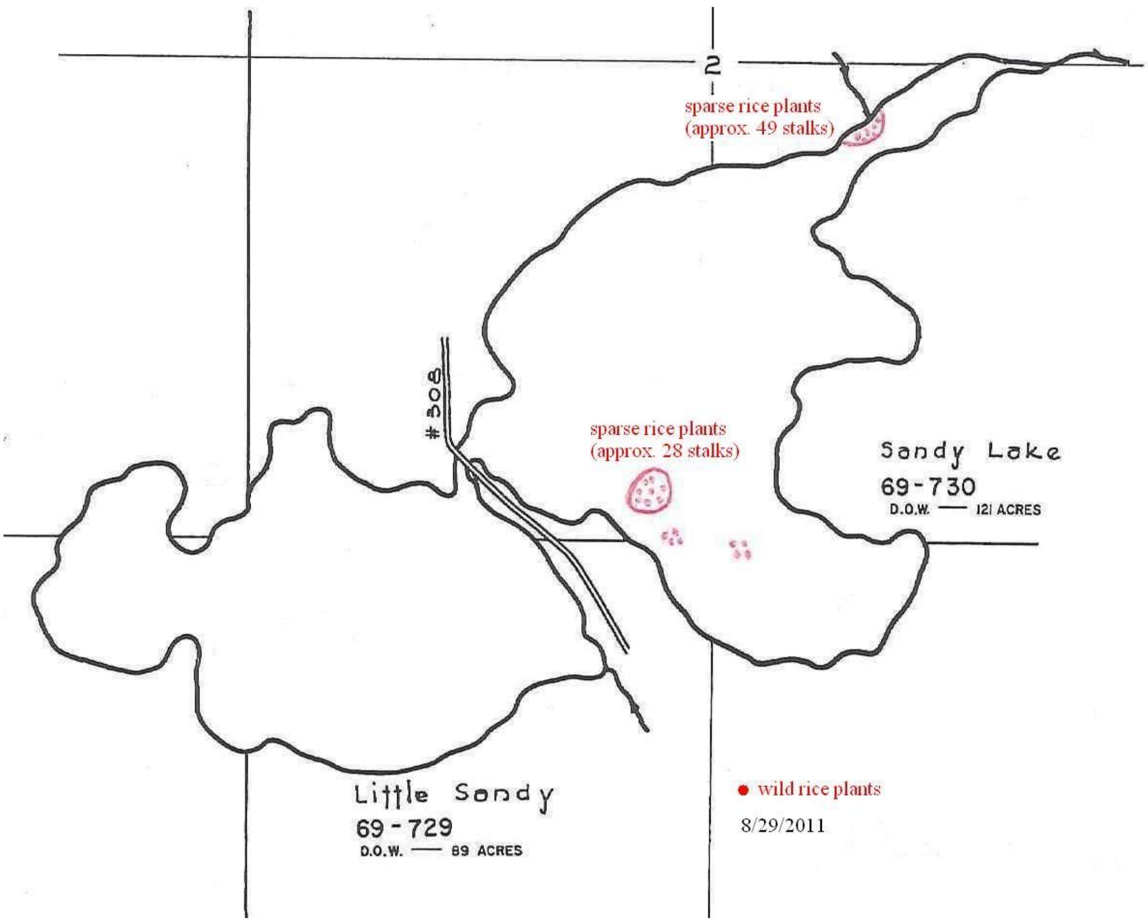

Figure 14: Wild Rice Locations in the Twin Lakes in 2011

In 2012, the survey to document wild rice presence on the lakes was conducted on August 27th. As in 2010 and 2011, wild rice plants (<50) were located on the northeast arm of Sandy Lake toward the outlet. Additional wild rice plants were located along portions of the eastern shore and southern end of the lake. For the first time documented since 2006 (although not surveyed in 2007-2009), wild rice was found in Little Sandy Lake in 2012 with two stalks growing along shore in the northwest bay of the lake. Please see Figure 15 for wild rice locations in 2012.

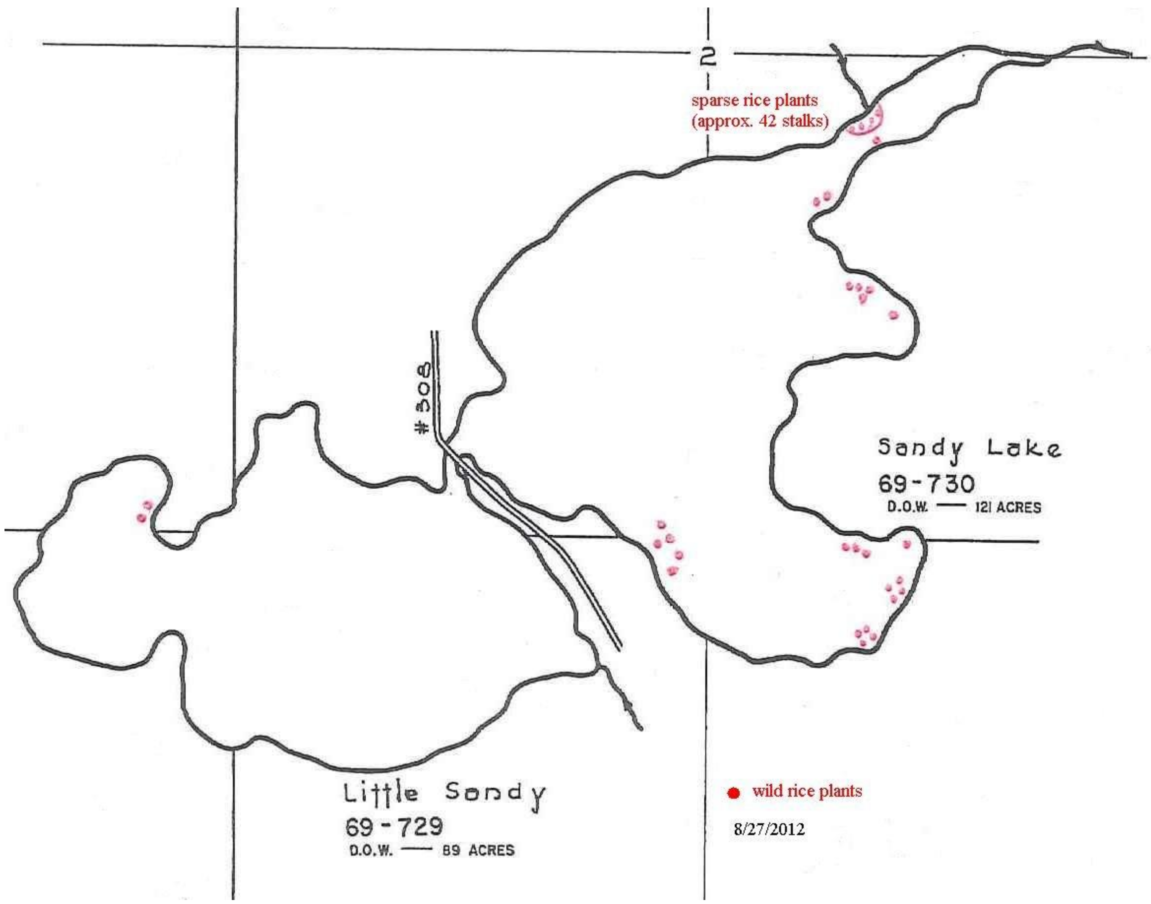

Figure 15: Wild Rice Locations in the Twin Lakes in 2012

The 2013 survey of wild rice presence was completed on August 26th. Some scattered wild rice plants were found along the northeast, east, and south shores of Sandy Lake. One notable difference from 2010-2012 was that no wild rice was observed in the northeast arm of Sandy Lake at the mouth of a small creek entering the system. One stalk of wild rice was found in Little Sandy Lake in 2013. Please see Figure 16 for wild rice locations in 2013.

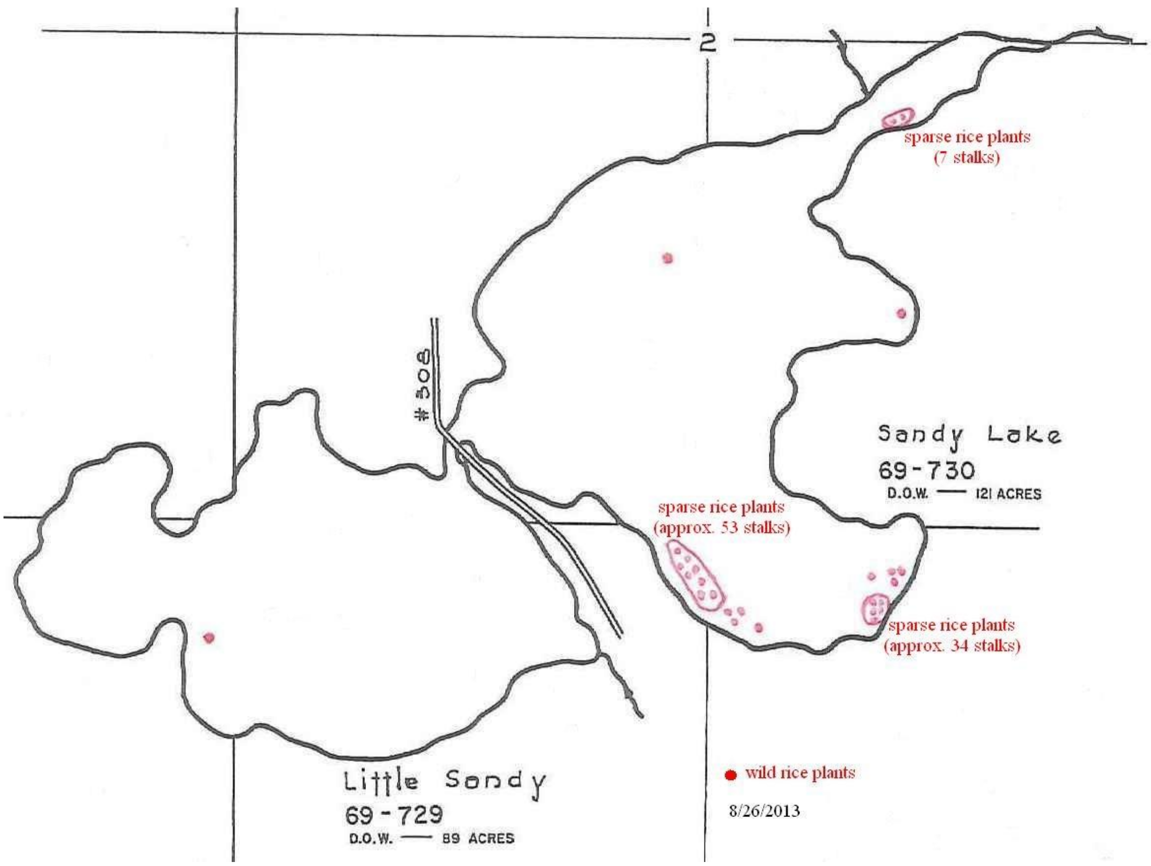

Figure 16: Wild Rice Locations in the Twin Lakes in 2013

In 2014, a total of 16 wild rice stalks was observed on Sandy Lake during the survey completed on August 21st. Wild rice plants were found along the southern shore of the lake, with one plant (short, just standing out of water) located in the northwest portion. For the first time since annual monitoring began in 2010, no wild rice was observed in the northeast arm of Sandy Lake. No wild rice was found in Little Sandy Lake in 2014. Please see Figure 17 for wild rice locations in 2014.

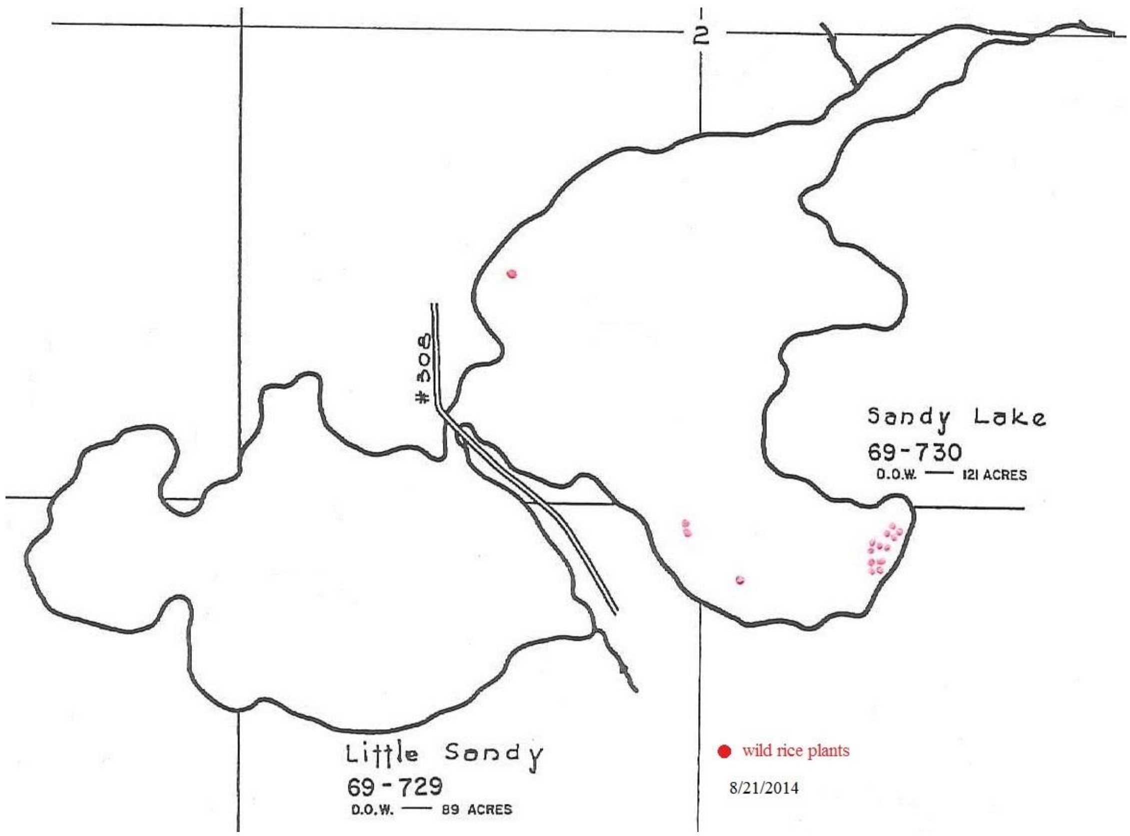

Figure 17: Wild Rice Locations in the Twin Lakes in 2014

In 2015, the survey for wild rice was conducted on August 20th. On Sandy Lake, a total of 36 stalks of wild rice was observed. Ten stalks were present in the northeast arm near the outlet, and one group of 26 stalks was found along the south shore. Some stalks were just standing out of the water or broken, and likely did not fully mature. No wild rice was seen in Little Sandy Lake in 2015. Please see Figure 18 for wild rice locations in 2015. U.S. Steel Minntac completed wild rice seeding on 10/23/15 using seed collected from the Sand River (approximately 40 lbs.). The seeding occurred in six small test plots, three in each lake. Success of wild rice growth was evaluated in 2016 and 2017.

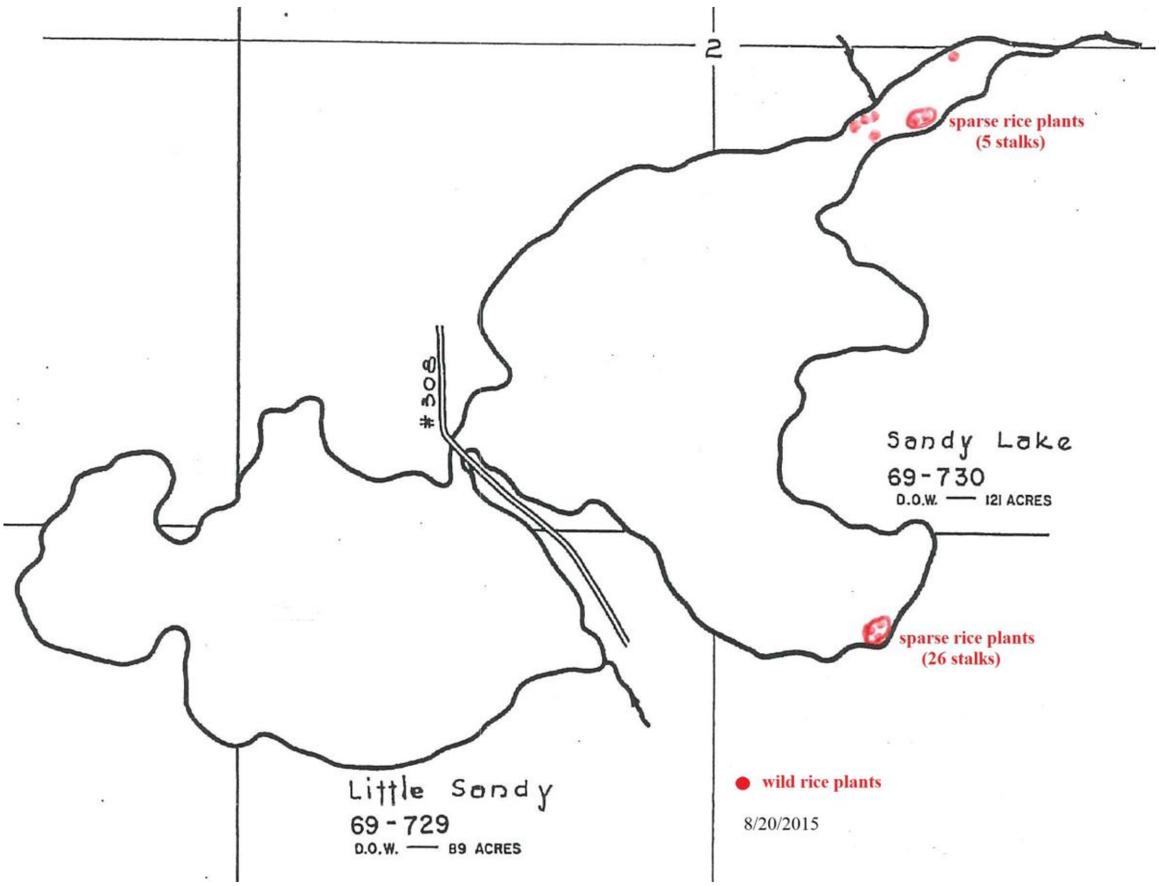

Figure 18: Wild Rice Locations in the Twin Lakes in 2015

During the 2016 wild rice survey completed on August 24th, wild rice was observed on both lakes. On Sandy Lake, 26 stalks of wild rice were seen outside of seeding plots. No wild rice was seen outside of seeding plots on Little Sandy Lake. Please see Figure 19 for wild rice locations in 2016. U.S. Steel Minntac completed wild rice seeding in fall 2015 in six test plots. Wild rice was observed in four of these plots, indicated on Figure 19.

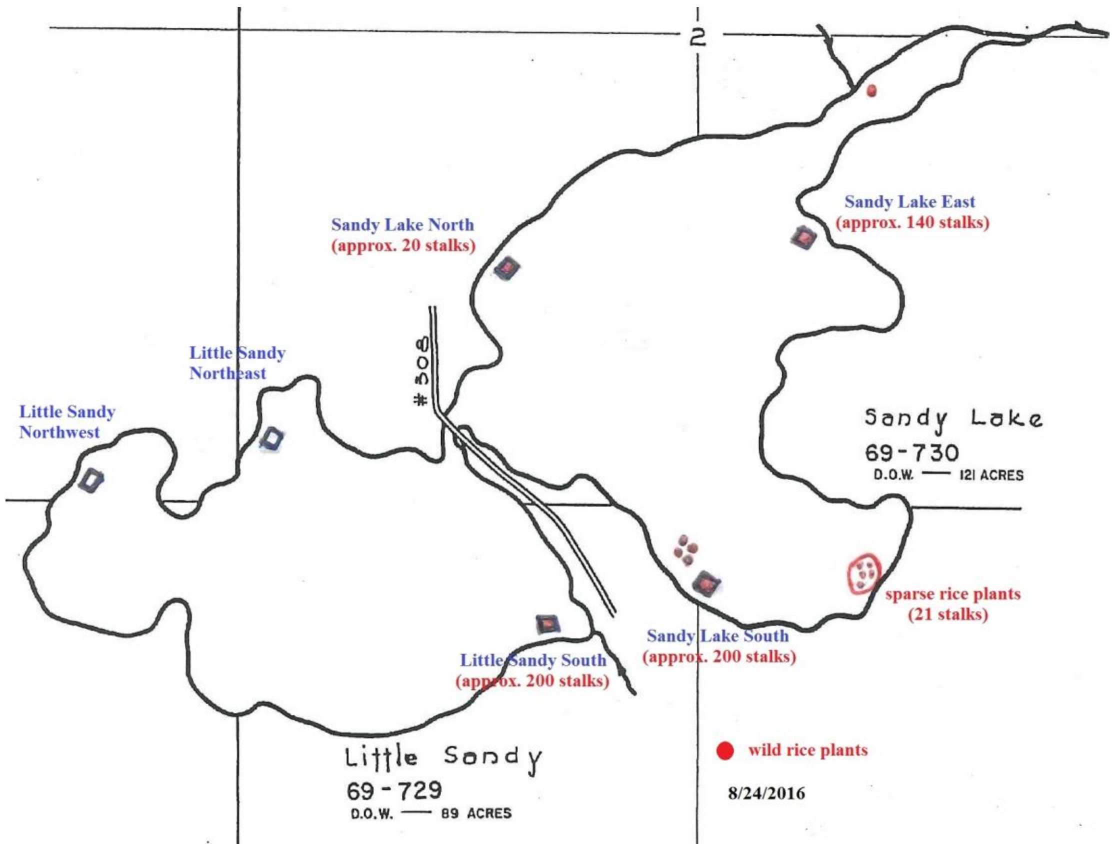

Figure 19: Wild Rice Locations in the Twin Lakes in 2016

The 2017 survey was completed on August 15th, one to two weeks earlier than previous years. The earlier survey, along with the fact that rice was generally late developing in 2017, resulted in many plants still in the floating-leaf stage or only beginning to stand during the field visit. The tallest plants observed were 3 feet and were flowering. On Sandy Lake, approximately 46 plants were identified outside of seeding plots. One wild rice stalk was seen outside of seeding plots on Little Sandy Lake near the bridge. Please see Figure 20 for wild rice locations in 2017. U.S. Steel Minntac completed wild rice seeding in fall 2015 in six test plots. Wild rice was observed in five of these plots, indicated on Figure 20. Most notable changes in the plots from 2016 to 2017 included declined wild rice growth in the Sandy Lake East plot, and increased wild rice growth in the Little Sandy Northeast plot.

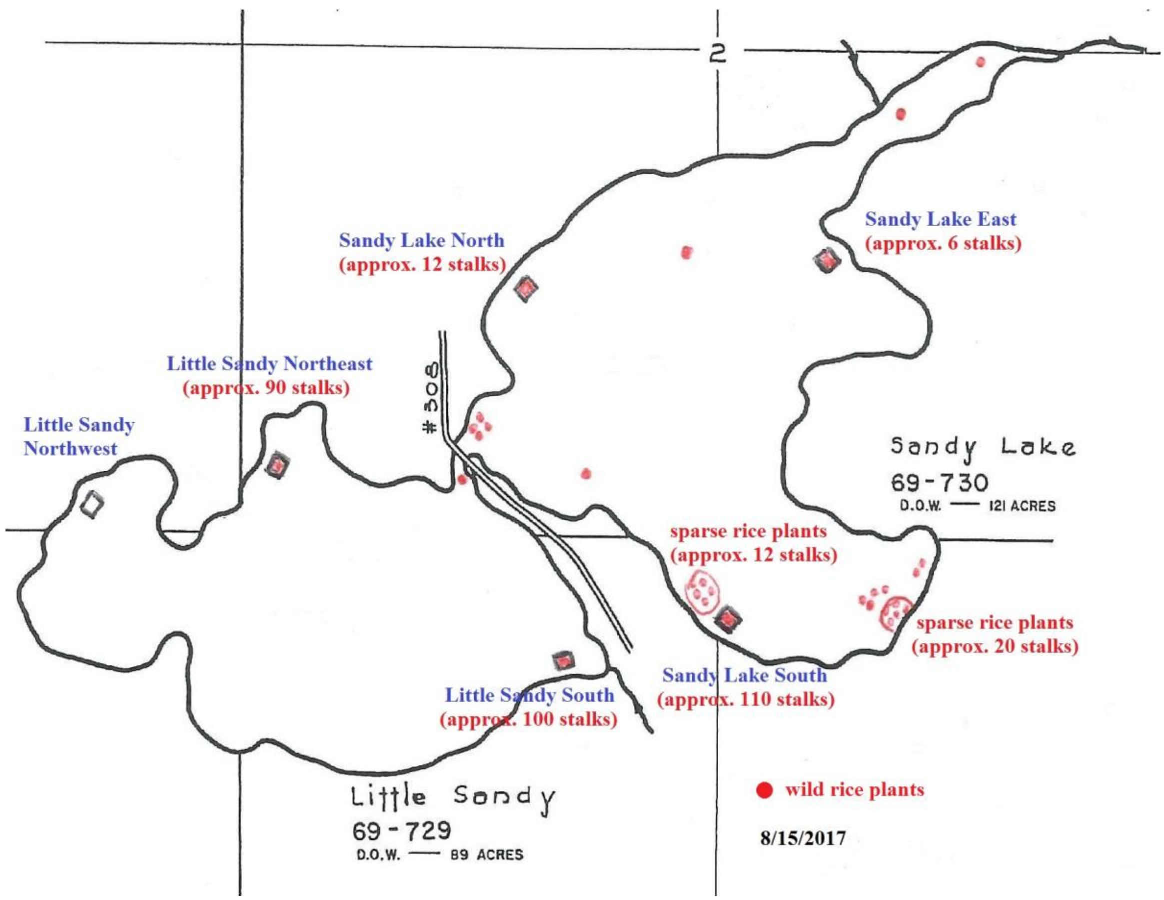

Figure 20: Wild Rice Locations in the Twin Lakes in 2017

Aerial Survey
To view the system and to document wild rice presence from the Minntac tailings basin downstream to Lake Vermilion, an aerial survey was conducted by helicopter each year in 2010-2014. In 2015-2017, flights were not conducted due to budget constraints. Flights began at the tailings basin, continued downstream to the Twin Lakes, followed the Sand River to its confluence with the Pike River, and then continued down the Pike River to the Pike River Flowage at its entrance into Lake Vermilion. In addition to taking digital photographs in 2010-2014, video of the flight was also recorded in 2010 and is available on a dvd.

Wild rice was identified in both the Sand River and Pike River during the aerial surveys. Viewed from the air, two stretches of the system have been identified to contain wild rice:

- Sand River / Pike River – Sand River from just downstream of County Road 303 crossing to confluence with Pike River, Pike River to County Road 792
- Pike River – from just upstream of County Road 367 crossing to Pike River Flowage

Some areas of wild rice may have been missed when viewed from the air. Please see Figure 21 for a map outlining areas containing wild rice.

Depending on the year, rice stands in portions of the rivers varied from sparse coverage to some areas with fair to good density. In 2017, observations from a 7/25/2017 field visit indicated good wild rice stands in the Sand River from County Road 303 downstream to Highway 169. Sparse wild rice stands were observed along the banks in the Pike River at the County Road 26 crossing on 8/10/2017. With no helicopter flight in 2017, a report for other parts of the system is unavailable.

Wild Rice Restoration
Under a permit requirement from the U.S. Army Corps of Engineers, U.S. Steel Minntac developed a Twin Lakes Wild Rice Restoration Opportunities Plan in 2013. The plan outlines activities to evaluate and potentially implement wild rice restoration in Sandy and Little Sandy lakes. Annual reports are available that summarize project activities completed by U.S. Steel Minntac since 2013.

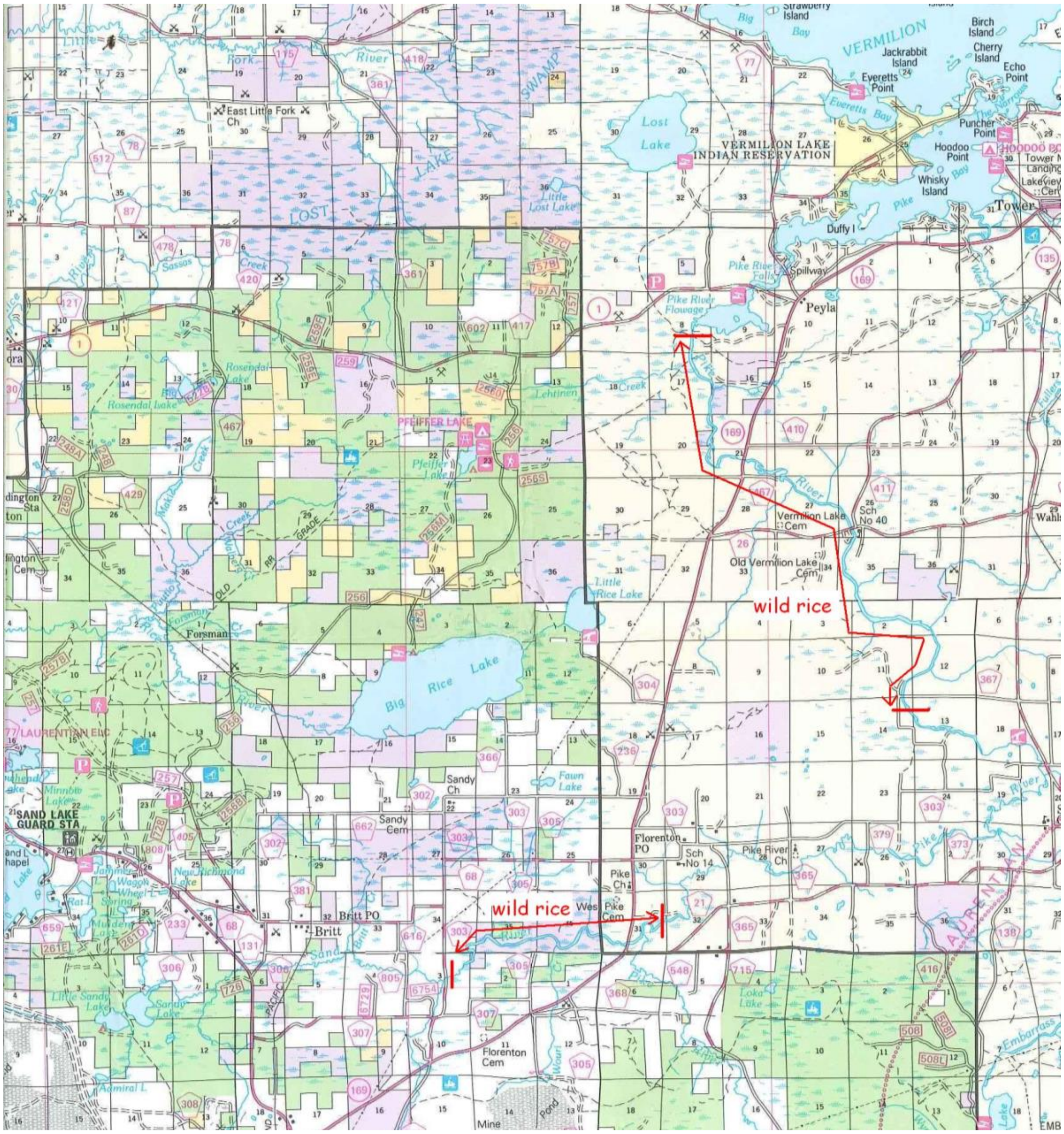

Figure 21: Wild Rice Locations in the Sand River and Pike River
(aerial surveys 9/9/2010, 9/6/2011, 9/11/2012, 9/6/2013, 9/6/2014)
United States Department of Agriculture, U.S. Forest Service, Superior National Forest map, 2003

Acknowledgments
In 2017, staff from the 1854 Treaty Authority (Nick Bogyo, Jeffrey Flory, Tyler Kaspar, Josh Mutchler, Saranda Oestreicher, Cassie Taplin) assisted with field activities.

Appendix 1

Photographs (2017)


access to bridge, looking south (9/7/17)


access to bridge, looking south (9/7/17)


access to bridge, looking south (9/7/17)


access to bridge, looking south (9/7/17)


access trail to Sandy Lake (9/7/17)


access to Sandy Lake (9/7/17)

Appendix 2

Water Sample Analysis in the Twin Lakes and Downstream Locations (2010-2017)

Table 2-1: Water Sample Analysis in the Twin Lakes (2010)

Twin 1	5/25/2010	6/24/2010	7/22/2010	8/26/2010	9/21/2010	10/25/2010	units
alkalinity (as CaCO3)	155	209	227	284	239	289	mg/L
chloride	65	75	78	107	73	110	mg/L
color	120	140	180	120	80	60	Pt-Co
nitrogen, nitrate + nitrite	< 0.02	0.04	< 0.05	< 0.05	< 0.01	< 0.01	mg/L
nitrogen, total	1.1	0.84	1.1	0.9	0.8	0.3	mg/L
nitrogen, total kjeldahl	1.1	0.8	1.1	0.9	0.8	0.3	mg/L
pH - lab	7.2	7.7	7.4	7.5	8.1	7.3	SU
solids, suspended volatile	1	1	1	2	< 1	< 1	mg/L
solids, total dissolved	810	1100	1030	1270	890	1370	mg/L
solids, total suspended	1	2	1	1	4	< 1	mg/L
specific conductance	1140	1320	1420	1690	1270	1810	umhos/cm
sulfate	387	453	450	661	360	584	mg/L
turbidity	1.7	1.2	0.3	0.5	0.7	0.8	NTU

Twin 2	5/25/2010	6/24/2010	7/22/2010	8/26/2010	9/21/2010	10/25/2010	units
alkalinity (as CaCO3)	151	150	171	228	236	242	mg/L
chloride	55	53	49	70.3	69	70	mg/L
color	50	60	140	120	80	70	Pt-Co
nitrogen, nitrate + nitrite	< 0.01	< 0.01	< 0.01	< 0.05	< 0.01	< 0.01	mg/L
nitrogen, total	1.0	0.6	1.1	0.9	0.8	0.5	mg/L
nitrogen, total kjeldahl	1.0	0.6	1.1	0.9	0.8	0.5	mg/L
pH - lab	8.2	8.5	8.5	8.7	8.4	8.4	SU
solids, suspended volatile	1	1	2	2	< 2	< 2	mg/L
solids, total dissolved	690	800	680	850	860	850	mg/L
solids, total suspended	< 1	1	1	1	< 2	< 2	mg/L
specific conductance	1030	982	980	1210	1210	1210	umhos/cm
sulfate	345	325	280	475	360	330	mg/L
turbidity	1.2	1.0	0.9	0.6	0.8	0.6	NTU

Twin 3	5/25/2010	6/24/2010	7/22/2010	8/26/2010	9/21/2010	10/25/2010	units
alkalinity (as CaCO3)	135	131	138	174	181	132	mg/L
chloride	51	50	46	53.7	55	58	mg/L
color	60	60	90	100	80	80	Pt-Co
nitrogen, nitrate + nitrite	< 0.01	< 0.01	< 0.01	< 0.05	< 0.01	< 0.01	mg/L
nitrogen, total	1.0	0.7	0.9	0.8	0.7	0.5	mg/L
nitrogen, total kjeldahl	1.0	0.7	0.9	0.8	0.7	0.5	mg/L
pH - lab	8.2	8.5	8.5	8.7	8.5	8.4	SU
solids, suspended volatile	1	1	2	1	< 2	< 1	mg/L
solids, total dissolved	640	730	600	650	670	700	mg/L
solids, total suspended	1	2	1	1	< 2	< 1	mg/L
specific conductance	959	876	875	957	986	1020	umhos/cm
sulfate	305	276	250	310	276	260	mg/L
turbidity	1.2	1.3	1.4	0.8	0.9	0.8	NTU

Twin 4	5/25/2010	6/24/2010	7/22/2010	8/26/2010	9/21/2010	10/25/2010	units
alkalinity (as CaCO3)	122	122	126	144	149	168	mg/L
chloride	44	45	39	44	46	56	mg/L
color	40	70	90	120	80	70	Pt-Co
nitrogen, nitrate + nitrite	< 0.01	< 0.05	< 0.05	< 0.05	< 0.01	< 0.01	mg/L
nitrogen, total	1.0	0.6	0.9	3.4	0.7	0.6	mg/L
nitrogen, total kjeldahl	1.0	0.6	0.9	3.4	0.7	0.6	mg/L
pH - lab	8.0	8.0	7.8	7.8	8.0	7.7	SU
solids, suspended volatile	2	1	3	2	2	2	mg/L
solids, total dissolved	540	680	530	510	550	640	mg/L
solids, total suspended	2	< 1	3	2	3	2	mg/L
specific conductance	838	812	800	777	838	977	umhos/cm
sulfate	252	247	210	234	236	226	mg/L
turbidity	2.0	1.2	3.2	2.4	3.2	1.0	NTU

Table 2-2: Water Sample Analysis in the Twin Lakes (2011)

Twin 1	5/24/2011	6/29/2011	7/27/2011	8/29/2011	9/28/2011	10/26/2011	units
alkalinity (as CaCO3)	133	143	250	301	315	269	mg/L
chloride	35	43	54	73	112	110	mg/L
color	120	160	280	140	60	40	Pt-Co
nitrogen, ammonia	0.06	<0.02	<0.02	<0.02	0.03	0.03	mg/L
nitrogen, nitrate + nitrite	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	mg/L
nitrogen, total	0.7	0.7	0.8	0.8	0.5	0.4	mg/L
nitrogen, total kjeldahl	0.7	0.7	0.8	0.8	0.5	0.4	mg/L
pH - lab	7.1	7.1	7.0	7.1	7.5	7.3	SU
phosphorus, total	0.031	0.022	0.045	0.037	0.030	0.019	mg/L
solids, suspended volatile	2	2	<1	1	1	1	mg/L
solids, total dissolved	490	610	870	1100	1420	1350	mg/L
solids, total suspended	4	5	<1	2	2	3	mg/L
specific conductance	773	848	1030	1330	1750	1700	umhos/cm
sulfate	208	220	237	355	559	561	mg/L
turbidity	2.9	0.75	1.6	1.0	0.8	1.1	NTU

Twin 2	5/24/2011	6/29/2011	7/27/2011	8/29/2011	9/28/2011	10/26/2011	units
alkalinity (as CaCO3)	111	131	180	204	208	217	mg/L
chloride	20	23	28	31	40	54	mg/L
color	70	60	140	80	60	50	Pt-Co
nitrogen, ammonia	0.05	<0.02	<0.02	0.02	0.03	<0.02	mg/L
nitrogen, nitrate + nitrite	0.06	<0.05	<0.05	<0.01	<0.05	<0.05	mg/L
nitrogen, total	0.76	0.6	1	1	0.8	0.6	mg/L
nitrogen, total kjeldahl	0.7	0.6	1	1	0.8	0.6	mg/L
pH - lab	7.9	8.1	7.9	8.3	8.4	8.3	SU
phosphorus, total	0.021	0.022	0.050	0.022	0.014	0.016	mg/L
solids, suspended volatile	2	2	3	1	<1	<1	mg/L
solids, total dissolved	350	410	550	580	610	680	mg/L
solids, total suspended	1	<3	4	2	<1	2	mg/L
specific conductance	566	621	680	733	814	990	umhos/cm
sulfate	140	130	140	150	179	247	mg/L
turbidity	1.0	1.3	1.8	0.9	0.6	1.3	NTU

Twin 3	5/24/2011	6/29/2011	7/27/2011	8/29/2011	9/28/2011	10/26/2011	units
alkalinity (as CaCO3)	93	103	140	155	148	168	mg/L
chloride	17	18	23	24	26	36	mg/L
color	70	70	160	70	60	60	Pt-Co
nitrogen, ammonia	0.03	0.02	0.23	<0.02	0.03	<0.02	mg/L
nitrogen, nitrate + nitrite	<0.05	<0.05	<0.05	<0.01	<0.01	<0.05	mg/L
nitrogen, total	0.8	0.7	1.2	1	0.8	0.6	mg/L
nitrogen, total kjeldahl	0.8	0.7	1.2	1	0.8	0.6	mg/L
pH - lab	8.1	7.8	7.7	8.1	8.3	8.4	SU
phosphorus, total	0.024	0.027	0.049	0.026	0.017	0.017	mg/L
solids, suspended volatile	2	2	3	<2	<2	1	mg/L
solids, total dissolved	290	330	420	430	430	490	mg/L
solids, total suspended	2	<3	3	2	<2	2	mg/L
specific conductance	468	483	545	553	572	739	umhos/cm
sulfate	110	103	107	109	110	166	mg/L
turbidity	1.7	1.8	3.1	1.7	0.9	1.2	NTU

Twin 4	5/24/2011	6/29/2011	7/27/2011	8/29/2011	9/28/2011	10/26/2011	units
alkalinity (as CaCO3)	81	77	130	136	103	141	mg/L
chloride	15	13	22	20	21	31	mg/L
color	80	80	140	80	50	60	Pt-Co
nitrogen, ammonia	0.04	<0.02	0.06	<0.02	0.03	0.05	mg/L
nitrogen, nitrate + nitrite	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	mg/L
nitrogen, total	0.8	0.6	0.9	0.9	0.8	0.6	mg/L
nitrogen, total kjeldahl	0.8	0.6	0.9	0.9	0.8	0.6	mg/L
pH - lab	7.5	7.1	7.4	7.3	7.6	8.0	SU
phosphorus, total	0.024	0.025	0.035	0.033	0.026	0.019	mg/L
solids, suspended volatile	2	2	2	1	5	<1	mg/L
solids, total dissolved	240	230	370	360	280	410	mg/L
solids, total suspended	1	<2	1	2	7	2	mg/L
specific conductance	394	288	492	471	388	611	umhos/cm
sulfate	85	63	89	78	61.4	127	mg/L
turbidity	2.0	2.4	2.0	1.2	1.5	1.9	NTU

Table 2-3: Water Sample Analysis in the Twin Lakes (2012)

Twin 1	5/23/2012	6/25/2012	7/23/2012	8/27/2012	9/26/2012	10/22/2012	units
alkalinity (as CaCO3)	139	117	189	231	226	237	mg/L
chloride	46	23	33	60	32	59	mg/L
color	60	240	250	200	90	80	Pt-Co
nitrogen, ammonia	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	mg/L
nitrogen, nitrate + nitrite	<0.01	<0.05	0.03	<0.01	0.02	0.03	mg/L
nitrogen, total	0.6	1.00	1.23	0.9	1.22	1.03	mg/L
nitrogen, total kjeldahl	0.6	1	1.2	0.9	1.2	1.0	mg/L
pH - lab	7.1	6.8	7.3	7.1	8	7.9	SU
phosphorus, total	0.017	0.034	0.044	0.034	0.020	0.018	mg/L
solids, suspended volatile	2	3	2	10	1	5	mg/L
solids, total dissolved	640	430	570	750	530	710	mg/L
solids, total suspended	2	3	3	17	2	10	mg/L
specific conductance	936	567	792	1050	782	1040	umhos/cm
sulfate	270	137	169	242	148	275	mg/L
turbidity	1.0	3.6	4.4	0.93	0.90	1.1	NTU

Twin 2	5/23/2012	6/25/2012	7/23/2012	8/27/2012	9/26/2012	10/22/2012	units
alkalinity (as CaCO3)	124	114	158	200	219	226	mg/L
chloride	33	18	15	23	28	44	mg/L
color	40	160	200	100	100	70	Pt-Co
nitrogen, ammonia	<0.07	0.09	0.1	<0.07	<0.07	<0.07	mg/L
nitrogen, nitrate + nitrite	<0.01	0.04	<0.01	<0.01	<0.01	0.03	mg/L
nitrogen, total	0.5	0.94	1.10	0.9	1.2	0.93	mg/L
nitrogen, total kjeldahl	0.5	0.9	1.1	0.9	1.2	0.9	mg/L
pH - lab	7.9	7.8	7.9	8.2	8.2	8.2	SU
phosphorus, total	0.019	0.020	0.022	0.013	0.014	0.016	mg/L
solids, suspended volatile	2	1	1	1	<1	<1	mg/L
solids, total dissolved	510	370	380	460	490	590	mg/L
solids, total suspended	2	1	1	1	<1	2	mg/L
specific conductance	775	521	530	655	726	884	umhos/cm
sulfate	210	121	87	104	131	210	mg/L
turbidity	1.7	1.6	1.3	0.73	0.70	1.3	NTU

Twin 3	5/23/2012	6/25/2012*	7/23/2012	8/27/2012	9/26/2012	10/22/2012	units
alkalinity (as CaCO3)	93	79	129	154	171	159	mg/L
chloride	28	16	14	19	20	22	mg/L
color	40	200	250	150	150	80	Pt-Co
nitrogen, ammonia	<0.07	<0.07	0.23	<0.07	<0.07	<0.07	mg/L
nitrogen, nitrate + nitrite	<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	mg/L
nitrogen, total	0.6	0.80	1.40	1.0	1.0	1.00	mg/L
nitrogen, total kjeldahl	0.6	0.8	1.4	1.0	1.0	1.0	mg/L
pH - lab	8.1	7.4	7.7	8.2	8.2	8.2	SU
phosphorus, total	0.023	0.018	0.029	0.019	0.016	0.017	mg/L
solids, suspended volatile	3	1	2	1	<1	1	mg/L
solids, total dissolved	400	290	340	370	370	370	mg/L
solids, total suspended	4	<1	2	1	1	2	mg/L
specific conductance	618	383	442	511	545	549	umhos/cm
sulfate	160	84	72.6	78.3	87	99	mg/L
turbidity	2.5	1.9	3.1	1.4	1.0	1.5	NTU

Twin 4	5/23/2012	6/25/2012*	7/23/2012	8/27/2012	9/26/2012	10/22/2012	units
alkalinity (as CaCO3)	73	90	104	117	126	102	mg/L
chloride	18	19	11	15	18	20	mg/L
color	60	160	250	200	80	60	Pt-Co
nitrogen, ammonia	<0.07	<0.07	0.15	0.1	<0.07	<0.07	mg/L
nitrogen, nitrate + nitrite	<0.01	<0.05	0.04	<0.01	<0.01	0.04	mg/L
nitrogen, total	0.6	0.80	1.34	1.1	1.0	0.94	mg/L
nitrogen, total kjeldahl	0.6	0.8	1.3	1.1	1.0	0.9	mg/L
pH - lab	7.7	7.7	7.4	7.3	7.5	7.4	SU
phosphorus, total	0.040	0.024	0.042	0.041	0.021	0.034	mg/L
solids, suspended volatile	2	<2	1	1	1	1	mg/L
solids, total dissolved	270	310	290	260	280	240	mg/L
solids, total suspended	3	2	2	2	2	2	mg/L
specific conductance	413	432	354	353	424	374	umhos/cm
sulfate	92.4	101	48	38	61	55	mg/L
turbidity	2.0	1.8	4.2	1.6	1.5	2.1	NTU

* possible reporting error on 6/25/12 for Twin 3 and Twin 4

* Analysis results reported from sampling at Twin 3 and Twin 4 on 6/25/2012 indicate a possible error in sampling or reporting. Twin 4 is located further downstream than Twin 3 from tailings basin releases. In every other sampling event conducted in 2010-2017, concentrations of several parameters have been lower in Twin 4 than in Twin 3. However, on this single occasion in question, results indicated concentrations higher in Twin 4 than in Twin 3. It is possible that reported results for Twin 3 and Twin 4 on 6/25/2012 were switched, but a source of an error could not be identified working from sampling field notes and with the laboratory. Heavy rains and historic flooding in the region a few days earlier may have been an impact to consider.

Table 2-4: Water Sample Analysis in the Twin Lakes (2013)

Twin 1	5/28/2013	6/26/2013	7/31/2013	8/26/2013	9/23/2013	10/23/2013	units
alkalinity (as CaCO3)	105	122	222	248	314	198	mg/L
chloride	37	34	57.2	75	124	57	mg/L
color	40	50	50	70	40	60	Pt-Co
nitrogen, ammonia	<0.02	<0.04	<0.02	<0.02	<0.01	0.03	mg/L
nitrogen, nitrate + nitrite	<0.01	0.01	<0.01	0.02	0.06	<0.01	mg/L
nitrogen, total	0.60	0.71	1.0	0.82	0.56	0.6	mg/L
nitrogen, total kjeldahl	0.6	0.7	1.0	0.8	0.5	0.6	mg/L
pH - lab	7.1	7.0	7.0	7.5	7.3	8.4	SU
phosphorus, total	0.018	0.022	0.064	0.025	0.020	0.014	mg/L
solids, suspended volatile	1	1	3	1	<1	1	mg/L
solids, total dissolved	440	490	790	820	1390	710	mg/L
solids, total suspended	2	1	4	2	1	1	mg/L
specific conductance	728	744	1140	1010	1890	1070	umhos/cm
sulfate	220	215	326	429	650	291	mg/L
turbidity	1.5	1.6	1.2	0.85	1.3	1.1	NTU

Twin 2	5/28/2013	6/26/2013	7/31/2013	8/26/2013	9/23/2013	10/23/2013	units
alkalinity (as CaCO3)	103	111	153	180	207	197	mg/L
chloride	25	25	27	32	47.3	49	mg/L
color	50	40	70	80	60	70	Pt-Co
nitrogen, ammonia	<0.02	<0.04	<0.02	<0.02	0.01	<0.01	mg/L
nitrogen, nitrate + nitrite	0.06	<0.01	0.07	<0.01	<0.01	<0.01	mg/L
nitrogen, total	0.66	0.7	0.9	0.9	0.7	0.7	mg/L
nitrogen, total kjeldahl	0.6	0.7	0.8	0.9	0.7	0.7	mg/L
pH - lab	8.0	7.8	8.3	8.7	8.6	8.7	SU
phosphorus, total	0.019	0.019	0.017	0.015	0.013	0.012	mg/L
solids, suspended volatile	2	1	<1	1	<1	<2	mg/L
solids, total dissolved	360	390	430	620	640	640	mg/L
solids, total suspended	3	2	1	2	1	2	mg/L
specific conductance	593	617	653	781	929	957	umhos/cm
sulfate	160	163	149	186	261	253	mg/L
turbidity	2.1	2.4	1.4	1.1	0.50	0.60	NTU

Twin 3	5/28/2013	6/26/2013	7/31/2013	8/26/2013	9/23/2013	10/23/2013	units
alkalinity (as CaCO3)	87	90	112	131	141	144	mg/L
chloride	23	21	24.7	24	27.9	30	mg/L
color	50	40	60	80	70	70	Pt-Co
nitrogen, ammonia	<0.02	<0.04	<0.02	<0.02	0.01	<0.01	mg/L
nitrogen, nitrate + nitrite	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	mg/L
nitrogen, total	0.60	0.9	0.7	0.9	0.8	0.6	mg/L
nitrogen, total kjeldahl	0.6	0.9	0.7	0.9	0.8	0.6	mg/L
pH - lab	8.0	7.8	8.5	8.8	8.9	8.8	SU
phosphorus, total	0.020	0.016	0.015	0.015	0.012	0.011	mg/L
solids, suspended volatile	2	2	2	2	<1	1	mg/L
solids, total dissolved	320	310	350	440	380	410	mg/L
solids, total suspended	3	2	2	2	1	1	mg/L
specific conductance	520	502	533	572	582	638	umhos/cm
sulfate	140	127	118	122	130	138	mg/L
turbidity	2.5	2.9	1.0	0.90	0.55	0.55	NTU

Twin 4	5/28/2013	6/26/2013	7/31/2013	8/26/2013	9/23/2013	10/23/2013	units
alkalinity (as CaCO3)	79	84	106	114	122	68	mg/L
chloride	21	20	21	20	25.4	17	mg/L
color	60	40	60	90	60	50	Pt-Co
nitrogen, ammonia	<0.02	<0.04	<0.02	<0.02	0.03	<0.01	mg/L
nitrogen, nitrate + nitrite	0.06	0.01	<0.01	<0.01	<0.01	0.02	mg/L
nitrogen, total	0.76	0.71	0.8	0.8	0.7	0.42	mg/L
nitrogen, total kjeldahl	0.7	0.7	0.8	0.8	0.7	0.4	mg/L
pH - lab	7.7	7.5	7.4	7.3	8.3	7.6	SU
phosphorus, total	0.022	0.019	0.020	0.024	0.015	0.014	mg/L
solids, suspended volatile	2	1	1	1	<1	<1	mg/L
solids, total dissolved	140	300	300	320	330	180	mg/L
solids, total suspended	2	1	1	2	<1	<1	mg/L
specific conductance	466	461	449	447	505	280	umhos/cm
sulfate	120	116	90.3	73	101	36	mg/L
turbidity	2.0	1.8	1.4	1.5	1.4	2.2	NTU

Table 2-5: Water Sample Analysis in the Twin Lakes (2014)

Twin 1	5/27/2014	6/30/2014	7/28/2014	8/21/2014	9/24/2014	10/27/2014	units
alkalinity (as CaCO3)	71	132	202	260	222	214	mg/L
chloride	31	30	51	74	58	81	mg/L
color	80	175	150	150	80	60	Pt-Co
nitrogen, ammonia	0.02	<0.02	<0.01	<0.01	0.02	0.01	mg/L
nitrogen, nitrate + nitrite	<0.05	0.01	<0.01	<0.01	<0.01	0.01	mg/L
nitrogen, total	0.8	1.01	0.9	0.8	0.8	1.31	mg/L
nitrogen, total kjeldahl	0.8	1.0	0.9	0.8	0.8	1.3	mg/L
pH - lab	7.7	7.1	7.0	7.2	7.6	7.6	SU
phosphorus, total	0.032	0.041	0.048	0.033	0.018	0.072	mg/L
solids, suspended volatile	1	2	2	<2	<1	7	mg/L
solids, total dissolved	420	470	820	950	NA	900	mg/L
solids, total suspended	2	4	2	2	<1	15	mg/L
specific conductance	457	693	1000	1340	1380	1290	umhos/cm
sulfate	184	180	313	391	317	419	mg/L
turbidity	2.5	2.2	2.3	2.2	0.70	7.3	NTU

Twin 2	5/27/2014	6/30/2014	7/28/2014	8/21/2014	9/24/2014	10/27/2014	units
alkalinity (as CaCO3)	93	110	138	156	161	183	mg/L
chloride	17	19	20	30	33	52	mg/L
color	70	150	100	100	100	70	Pt-Co
nitrogen, ammonia	<0.01	0.04	<0.01	0.02	0.01	<0.01	mg/L
nitrogen, nitrate + nitrite	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	mg/L
nitrogen, total	0.6	1.0	1.1	1.1	0.8	0.9	mg/L
nitrogen, total kjeldahl	0.6	1.0	1.1	1.1	0.8	0.9	mg/L
pH - lab	7.1	7.9	7.7	8.1	8.4	8.2	SU
phosphorus, total	0.016	0.022	0.024	0.026	0.019	0.020	mg/L
solids, suspended volatile	1	1	2	<2	1	1	mg/L
solids, total dissolved	300	360	420	450	520	640	mg/L
solids, total suspended	2	3	3	<2	<1	2	mg/L
specific conductance	638	543	571	658	763	949	umhos/cm
sulfate	128	134	137	179	182	274	mg/L
turbidity	1.1	1.8	2.5	2.3	1.1	1.2	NTU

Twin 3	5/27/2014	6/30/2014	7/28/2014	8/21/2014	9/24/2014	10/27/2014	units
alkalinity (as CaCO3)	57	84	102	114	119	141	mg/L
chloride	16	16	17	18	21	34	mg/L
color	90	200	150	150	150	80	Pt-Co
nitrogen, ammonia	<0.01	0.13	0.08	0.04	0.03	0.02	mg/L
nitrogen, nitrate + nitrite	<0.05	<0.01	0.02	<0.01	0.02	0.02	mg/L
nitrogen, total	0.7	1.2	1.32	1.1	0.92	1.02	mg/L
nitrogen, total kjeldahl	0.7	1.2	1.3	1.1	0.9	1.0	mg/L
pH - lab	7.6	7.9	8.0	8.1	8.2	8.1	SU
phosphorus, total	0.014	0.032	0.028	0.022	0.017	0.021	mg/L
solids, suspended volatile	1	3	2	<1	1	<1	mg/L
solids, total dissolved	260	290	330	330	340	440	mg/L
solids, total suspended	1	6	2	<1	<1	1	mg/L
specific conductance	379	436	440	469	528	674	umhos/cm
sulfate	102	102	103	96	109	172	mg/L
turbidty	0.95	3.2	2.0	1.6	1.0	1.6	NTU

Twin 4	5/27/2014	6/30/2014	7/28/2014	8/21/2014	9/24/2014	10/27/2014	units
alkalinity (as CaCO3)	56	77	86	96	88	81	mg/L
chloride	16	15	15	15	17	20	mg/L
color	80	250	200	150	100	60	Pt-Co
nitrogen, ammonia	<0.01	0.07	0.03	0.04	0.01	0.06	mg/L
nitrogen, nitrate + nitrite	<0.05	<0.05	<0.01	<0.05	<0.05	0.02	mg/L
nitrogen, total	0.7	1.1	1.1	1.1	0.8	0.82	mg/L
nitrogen, total kjeldahl	0.7	1.1	1.1	1.1	0.8	0.8	mg/L
pH - lab	7.5	7.5	7.3	7.3	7.6	7.3	SU
phosphorus, total	0.018	0.033	0.031	0.046	0.023	0.025	mg/L
solids, suspended volatile	<1	<2	1	<2	1	<2	mg/L
solids, total dissolved	260	260	280	230	260	240	mg/L
solids, total suspended	2	2	1	2	1	2	mg/L
specific conductance	375	375	346	328	386	369	umhos/cm
sulfate	100	79	60	44	67	72	mg/L
turbidity	1.1	3.2	3.6	2.5	1.9	2.4	NTU

Table 2-6: Water Sample Analysis in the Twin Lakes (2015)

Twin 1	6/25/2015	8/20/2015	10/19/2015	units
alkalinity (as CaCO3)	148	122	244	mg/L
chloride	58	50	86	mg/L
color	70	50	60	Pt-Co
nitrogen, ammonia	<0.01	<0.01	0.05	mg/L
nitrogen, nitrate + nitrite	<0.01	<0.01	<0.01	mg/L
nitrogen, total	0.7	0.7	0.5	mg/L
nitrogen, total kjeldahl	0.7	0.7	0.5	mg/L
pH - lab	7.4	7.0	7.7	SU
phosphorus, total	0.017	0.029	0.017	mg/L
solids, suspended volatile	<1	2	<1	mg/L
solids, total dissolved	730	840	1070	mg/L
solids, total suspended	<1	4	2	mg/L
specific conductance	1080	1100	1510	umhos/cm
sulfate	386	405	590	mg/L
turbidity	1.0	4.7	5.1	NTU

Twin 2	6/25/2015	8/20/2015	10/19/2015	units
alkalinity (as CaCO3)	124	182	196	mg/L
chloride	35	43	50	mg/L
color	70	60	80	Pt-Co
nitrogen, ammonia	<0.01	<0.01	<0.01	mg/L
nitrogen, nitrate + nitrite	<0.01	<0.01	<0.01	mg/L
nitrogen, total	0.7	0.8	0.6	mg/L
nitrogen, total kjeldahl	0.7	0.8	0.6	mg/L
pH - lab	8.1	8.5	8.3	SU
phosphorus, total	0.015	0.018	0.019	mg/L
solids, suspended volatile	1	2	1	mg/L
solids, total dissolved	500	620	670	mg/L
solids, total suspended	1	2	2	mg/L
specific conductance	765	915	1010	umhos/cm
sulfate	253	273	360	mg/L
turbidity	2.1	2.0	1.9	NTU

Twin 3	6/25/2015	8/20/2015	10/19/2015	units
alkalinity (as CaCO3)	107	119	160	mg/L
chloride	33	31	40	mg/L
color	60	70	80	Pt-Co
nitrogen, ammonia	0.04	<0.01	<0.01	mg/L
nitrogen, nitrate + nitrite	<0.01	<0.01	<0.01	mg/L
nitrogen, total	0.7	0.9	0.7	mg/L
nitrogen, total kjeldahl	0.7	0.9	0.7	mg/L
pH - lab	8.2	8.4	8.1	SU
phosphorus, total	0.020	0.018	0.024	mg/L
solids, suspended volatile	<1	<1	1	mg/L
solids, total dissolved	440	450	550	mg/L
solids, total suspended	<1	1	4	mg/L
specific conductance	677	663	1000	umhos/cm
sulfate	209	171	270	mg/L
turbidity	1.3	1.2	3.4	NTU

Twin 4	6/25/2015	8/20/2015	10/19/2015	units
alkalinity (as CaCO3)	95	28	144	mg/L
chloride	29	13	34	mg/L
color	70	150	90	Pt-Co
nitrogen, ammonia	<0.01	0.01	0.02	mg/L
nitrogen, nitrate + nitrite	<0.01	<0.01	<0.01	mg/L
nitrogen, total	0.8	0.7	0.6	mg/L
nitrogen, total kjeldahl	0.8	0.7	0.6	mg/L
pH - lab	7.8	7.0	8.0	SU
phosphorus, total	0.020	0.023	0.023	mg/L
solids, suspended volatile	2	<2	<1	mg/L
solids, total dissolved	360	190	470	mg/L
solids, total suspended	2	2	3	mg/L
specific conductance	566	249	715	umhos/cm
sulfate	168	45.6	220	mg/L
turbidity	2.2	5.4	4.3	NTU

Table 2-7: Water Sample Analysis in the Twin Lakes (2016)

Twin 1	6/23/2016	8/24/2016	10/25/2016	units
alkalinity (as CaCO3)	114	234	200	mg/L
chloride	31.9	55.2	66.4	mg/L
color	150	200	150	Pt-Co
nitrogen, ammonia	ND	ND	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	1.0	0.85	ND	mg/L
nitrogen, total kjeldahl	1.0	0.84	ND	mg/L
pH - lab	7.3	7.3	7.6	SU
phosphorus, total	0.024	0.034	0.022	mg/L
solids, suspended volatile	ND	1.0	2.8	mg/L
solids, total dissolved	472	814	762	mg/L
solids, total suspended	1.2	1.2	5.0	mg/L
specific conductance	679	1070	1100	umhos/cm
sulfate	217	304	347	mg/L
turbidity	3.1	3.3	5.6	NTU

Twin 2	6/23/2016	8/24/2016	10/25/2016	units
alkalinity (as CaCO3)	122	194	194	mg/L
chloride	25.9	24.0	41.2	mg/L
color	40.0	300	150	Pt-Co
nitrogen, ammonia	ND	0.14	0.18	mg/L
nitrogen, nitrate + nitrite	ND	ND	0.020	mg/L
nitrogen, total	0.82	1.3	0.73	mg/L
nitrogen, total kjeldahl	0.82	1.3	0.71	mg/L
pH - lab	7.9	8.1	8.2	SU
phosphorus, total	0.014	0.023	0.010	mg/L
solids, suspended volatile	ND	2.0	ND	mg/L
solids, total dissolved	428	486	570	mg/L
solids, total suspended	1.8	2.4	1.0	mg/L
specific conductance	628	640	818	umhos/cm
sulfate	194	126	211	mg/L
turbidity	1.8	3.2	1.7	NTU

Twin 3	6/23/2016	8/24/2016	10/25/2016	units
alkalinity (as CaCO3)	93.2	145	158	mg/L
chloride	24.5	19.2	33.4	mg/L
color	90.0	375	100	Pt-Co
nitrogen, ammonia	ND	0.40	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.68	1.6	0.81	mg/L
nitrogen, total kjeldahl	0.67	1.5	0.80	mg/L
pH - lab	8.0	7.8	8.3	SU
phosphorus, total	0.011	0.027	0.012	mg/L
solids, suspended volatile	ND	1.2	ND	mg/L
solids, total dissolved	348	386	454	mg/L
solids, total suspended	1.0	1.0	ND	mg/L
specific conductance	525	481	663	umhos/cm
sulfate	158	82.7	148	mg/L
turbidity	1.1	3.7	1.9	NTU

Twin 4	6/23/2016	8/24/2016	10/25/2016	units
alkalinity (as $CaCO_3$)	89.0	132	143	mg/L
chloride	22.7	17.5	30.4	mg/L
color	110	300	150	Pt-Co
nitrogen, ammonia	ND	0.34	0.18	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.63	1.4	0.73	mg/L
nitrogen, total kjeldahl	0.63	1.4	0.72	mg/L
pH - lab	7.8	7.8	8.1	SU
phosphorus, total	0.014	0.029	0.015	mg/L
solids, suspended volatile	ND	1.0	1.0	mg/L
solids, total dissolved	314	360	410	mg/L
solids, total suspended	1.6	1.0	1.6	mg/L
specific conductance	477	435	616	umhos/cm
sulfate	138	70.9	132	mg/L
turbidity	2.1	6.8	2.8	NTU

Table 2-8: Water Sample Analysis in the Twin Lakes (2017)

Twin 1	6/27/2017	8/15/2017	10/26/2017	units
alkalinity (as CaCO3)	137	283	180	mg/L
chloride	36.9	93.8	50.6	mg/L
color	150	70.0	200	Pt-Co
nitrogen, ammonia	0.14	0.12	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.82	ND	0.68	mg/L
nitrogen, total kjeldahl	0.81	ND	0.68	mg/L
pH - lab	7.1	8.1	7.4	SU
phosphorus, total	0.025	0.011	0.025	mg/L
solids, suspended volatile	1.6	2.4	1.0	mg/L
solids, total dissolved	536	1230	724	mg/L
solids, total suspended	1.6	4.6	1.0	mg/L
specific conductance	823	1740	998	umhos/cm
sulfate	251	589	297	mg/L
turbidity	2.3	1.7	3.8	NTU

Twin 2	6/27/2017	8/15/2017	10/26/2017	units
alkalinity (as CaCO3)	141	206	165	mg/L
chloride	23.5	37.7	30.9	mg/L
color	150	100	150	Pt-Co
nitrogen, ammonia	0.11	ND	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.71	0.85	0.70	mg/L
nitrogen, total kjeldahl	0.71	0.85	0.70	mg/L
pH - lab	7.1	8.8	8.2	SU
phosphorus, total	0.014	0.012	0.011	mg/L
solids, suspended volatile	1.2	ND	1.0	mg/L
solids, total dissolved	436	602	538	mg/L
solids, total suspended	1.4	ND	ND	mg/L
specific conductance	647	978	745	umhos/cm
sulfate	170	242	189	mg/L
turbidity	1.3	1.1	1.2	NTU

Twin 3	6/27/2017	8/15/2017	10/26/2017	units
alkalinity (as CaCO3)	104	146	129	mg/L
chloride	21.6	24.6	27.8	mg/L
color	175	125	200	Pt-Co
nitrogen, ammonia	0.14	ND	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.84	0.89	0.77	mg/L
nitrogen, total kjeldahl	0.84	0.89	0.77	mg/L
pH - lab	7.0	8.6	8.1	SU
phosphorus, total	0.016	0.016	0.015	mg/L
solids, suspended volatile	1.0	ND	ND	mg/L
solids, total dissolved	348	422	432	mg/L
solids, total suspended	ND	ND	1.2	mg/L
specific conductance	521	648	610	umhos/cm
sulfate	131	132	145	mg/L
turbidity	1.3	1.2	2.3	NTU

Twin 4	6/27/2017	8/15/2017	10/26/2017	units
alkalinity (as CaCO3)	92.9	105	120	mg/L
chloride	19.6	19.7	26.2	mg/L
color	250	100	200	Pt-Co
nitrogen, ammonia	ND	ND	ND	mg/L
nitrogen, nitrate + nitrite	ND	ND	ND	mg/L
nitrogen, total	0.75	0.73	0.70	mg/L
nitrogen, total kjeldahl	0.74	0.72	0.69	mg/L
pH - lab	6.8	8.1	7.9	SU
phosphorus, total	0.018	0.025	0.015	mg/L
solids, suspended volatile	ND	ND	ND	mg/L
solids, total dissolved	320	248	384	mg/L
solids, total suspended	1.2	1.2	1.4	mg/L
specific conductance	467	419	564	umhos/cm
sulfate	115	66.4	130	mg/L
turbidity	3.0	2.0	2.6	NTU

Table 2-9: Water Sample Analysis in the Sand River, Pike River, and Pike River Flowage (2010-2017)

10/25/2010	Sand	Pike	Pike Flowage	units
alkalinity (as CaCO3)	61	62	47	mg/L
chloride	27	16	14	mg/L
color	140	140	140	Pt-Co
nitrogen, nitrate + nitrite	< 0.01	0.01	< 0.01	mg/L
nitrogen, total	0.7	0.61	0.7	mg/L
nitrogen, total kjeldahl	0.7	0.6	0.7	mg/L
pH - lab	7.3	7.4	7.4	SU
solids, suspended volatile	2	3	< 1	mg/L
solids, total dissolved	270	190	170	mg/L
solids, total suspended	3	8	1	mg/L
specific conductance	426	262	196	umhos/cm
sulfate	79	40	27	mg/L
turbidity	9.7	9.5	3.9	NTU

10/26/2011	Sand	Pike	Pike Flowage	units
alkalinity (as CaCO3)	109	86	60	mg/L
chloride	28	21	13	mg/L
color	80	80	70	Pt-Co
nitrogen, ammonia	0.02	<0.02	0.04	mg/L
nitrogen, nitrate + nitrite	<0.05	<0.05	<0.05	mg/L
nitrogen, total	0.6	0.6	0.6	mg/L
nitrogen, total kjeldahl	0.6	0.6	0.6	mg/L
pH - lab	7.4	7.4	7.5	SU
phosphorus, total	0.027	0.025	0.027	mg/L
solids, suspended volatile	2	2	<2	mg/L
solids, total dissolved	320	230	150	mg/L
solids, total suspended	5	5	4	mg/L
specific conductance	469	328	202	umhos/cm
sulfate	81	43	19	mg/L
turbidity	6.4	6.1	4.6	NTU

10/22/2012	Sand	Pike	Pike Flowage	units
alkalinity (as CaCO3)	101	66	59	mg/L
chloride	26	12	13	mg/L
color	150	60	150	Pt-Co
nitrogen, ammonia	<0.07	<0.07	<0.07	mg/L
nitrogen, nitrate + nitrite	<0.01	0.07	0.01	mg/L
nitrogen, total	0.90	0.47	0.81	mg/L
nitrogen, total kjeldahl	0.9	0.4	0.8	mg/L
pH - lab	7.8	7.6	7.7	SU
phosphorus, total	0.046	0.025	0.035	mg/L
solids, suspended volatile	3	2	1	mg/L
solids, total dissolved	230	100	200	mg/L
solids, total suspended	6	6	3	mg/L
specific conductance	344	193	193	umhos/cm
sulfate	32	13	15	mg/L
turbidity	19	7.4	6.7	NTU

10/23/2013	Sand	Pike	Pike Flowage	units
alkalinity (as CaCO3)	84	73	58	mg/L
chloride	28	20	12	mg/L
color	90	80	100	Pt-Co
nitrogen, ammonia	<0.01	<0.01	<0.01	mg/L
nitrogen, nitrate + nitrite	0.02	0.03	0.02	mg/L
nitrogen, total	0.82	0.63	0.72	mg/L
nitrogen, total kjeldahl	0.8	0.6	0.7	mg/L
pH - lab	7.4	7.5	7.7	SU
phosphorus, total	0.035	0.026	0.036	mg/L
solids, suspended volatile	2	2	2	mg/L
solids, total dissolved	220	180	140	mg/L
solids, total suspended	4	3	8	mg/L
specific conductance	323	252	178	umhos/cm
sulfate	27.4	16.8	7.1	mg/L
turbidity	9.8	6.2	5.0	NTU

10/27/2014	Sand	Pike	Pike Flowage	units
alkalinity (as CaCO3)	84	67	66	mg/L
chloride	28	20.4	18.5	mg/L
color	80	60	100	Pt-Co
nitrogen, ammonia	0.02	0.02	0.01	mg/L
nitrogen, nitrate + nitrite	0.02	0.05	0.03	mg/L
nitrogen, total	0.92	0.85	0.93	mg/L
nitrogen, total kjeldahl	0.9	0.8	0.9	mg/L
pH - lab	7.5	7.4	7.6	SU
phosphorus, total	0.034	0.029	0.040	mg/L
solids, suspended volatile	2	1	2	mg/L
solids, total dissolved	260	210	160	mg/L
solids, total suspended	5	4	3	mg/L
specific conductance	401	297	212	umhos/cm
sulfate	73.2	48.4	11	mg/L
turbidity	7.4	7.0	5.6	NTU

10/19/2015	Sand	Pike	Pike Flowage	units
alkalinity (as CaCO3)	86	66	56	mg/L
chloride	30	20	17	mg/L
color	140	160	200	Pt-Co
nitrogen, ammonia	<0.01	<0.01	0.03	mg/L
nitrogen, nitrate + nitrite	<0.01	0.02	0.04	mg/L
nitrogen, total	0.8	0.72	0.94	mg/L
nitrogen, total kjeldahl	0.8	0.7	0.9	mg/L
pH - lab	7.3	7.5	7.4	SU
phosphorus, total	0.026	0.034	0.041	mg/L
solids, suspended volatile	<1	2	<2	mg/L
solids, total dissolved	280	220	190	mg/L
solids, total suspended	1	6	3	mg/L
specific conductance	288	251	416	umhos/cm
sulfate	87.6	46.9	31.9	mg/L
turbidity	5.3	8.2	5.3	NTU

10/25/2016	Sand	Pike	Pike Flowage	units
alkalinity (as CaCO3)	84.9	70.4	62.1	mg/L
chloride	28.3	18.9	17.3	mg/L
color	200	150	200	Pt-Co
nitrogen, ammonia	0.10	ND	ND	mg/L
nitrogen, nitrate + nitrite	0.040	0.068	0.068	mg/L
nitrogen, total	0.91	0.71	0.91	mg/L
nitrogen, total kjeldahl	0.87	0.64	0.84	mg/L
pH - lab	7.4	7.6	7.6	SU
phosphorus, total	0.029	0.021	0.025	mg/L
solids, suspended volatile	1.6	2.4	ND	mg/L
solids, total dissolved	228	174	184	mg/L
solids, total suspended	2.6	5.2	1.4	mg/L
specific conductance	341	245	218	umhos/cm
sulfate	43.8	22.1	17.9	mg/L
turbidity	6.8	6.0	4.1	NTU

10/26/2017	Sand	Pike	Pike Flowage	units
alkalinity (as CaCO3)	85.8	63.6	49.5	mg/L
chloride	26.1	16.4	13.5	mg/L
color	250	250	250	Pt-Co
nitrogen, ammonia	0.10	ND	ND	mg/L
nitrogen, nitrate + nitrite	ND	0.033	0.031	mg/L
nitrogen, total	0.98	0.96	0.88	mg/L
nitrogen, total kjeldahl	0.97	0.93	0.85	mg/L
pH - lab	7.4	7.5	7.5	SU
phosphorus, total	0.035	0.027	0.026	mg/L
solids, suspended volatile	5.2	10.6	1.4	mg/L
solids, total dissolved	224	140	172	mg/L
solids, total suspended	8.0	45.2	8.4	mg/L
specific conductance	335	231	188	umhos/cm
sulfate	36.9	19.2	15.1	mg/L
turbidity	7.8	17.5	6.2	NTU